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The Association of Working Memory and Anxiety with Skill Acquisition and Transfer in Young and Older Adults

Isabelle Valk

A Thesis Submitted in Partial Fulfillment of the Requirements for the

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The Association of Working Memory and Anxiety with Skill Acquisition and Transfer in Young and Older adults

Abstract

Two studies, involving a total of 184 adults between 17 and 89 years of age, were conducted to determine whether age differences in skill acquisition and transfer could be related to age differences in working memory functioning and anxiety. In both experiments, working memory functioning was measured using the Digit Span task (Wechsler, 1997) and the Reading Span task (Daneman & Carpenter, 1980), while anxiety levels were measured using the State-Trait Anxiety Inventory (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). Participants were required to perform a mental arithmetic task in Experiment 1, and a visual numerosity task in Experiment 2. In each experiment, participants received 240 trials of the task during a training phase (in which one set of stimuli were used) and 240 trials during a transfer phase (in which a second set of stimuli were used). The results from both studies revealed that partial positive transfer occurred from one phase to another for both young and older adults. This indicates that both age groups learned the skills in a similar way: using a combination of general and specific learning. Moreover, the older adults in both experiments became faster with practice, they generally improved as much as younger adults with practice, and they were able to achieve the same or better levels of accuracy compared to younger adults. This suggests that healthy older adults possess the ability to learn new skills. When scores for working memory span and anxiety were analysed, working memory span was found to correlate significantly with the accuracy levels and reaction times of the young age group in Experiment 1, and of both age groups in Experiment 2. Similarly, anxiety levels were related to reaction times for both age groups in both experiments, with higher levels of anxiety also associated with smaller working memory spans for the young adults in both experiments. These results suggest that both working memory span and anxiety have an impact on the performance of participants, and can account for some of the age differences observed during skill acquisition and transfer.

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Declaration

I certify that this thesis does not, to the best of my knowledge and belief:

(i) incorporate without acknowledgment any material previously submitted for a degree or diploma in any institution of higher education;

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Table of Contents

List of Tables

Appendixes

Preface

Learning is an integral part of life. Indeed, it is difficult to imagine what living would be like without learning. For example, if learning stopped in late adulthood, our knowledge base from that point in time would remain fixed. Therefore, we would not be able to add information to what we already know, such as the names of new politicians, or current affairs in other countries. Furthermore, older people would be unable to acquire new skills, such as playing golf, operating a wheelchair, mastering a new lock, or using a computer. Therefore, learning is a critical part of life, which allows humans to adapt to their changing environments (Kausler, 1994).

Fortunately, learning is a process that does continue throughout the lifespan. According to Kausler (1994), older people are highly active learners if they remain healthy. That is, "they acquire new information, they learn new recreational skills, they learn to operate new gadgets and devices, they learn their way around new neighbourhoods, they learn to avoid hazardous obstacles, they learn to relate new names to new faces, and they also learn new prejudices and fears " (Kausler, 1994, p. 2). Similarly, Rabbitt (1997) states that "older individuals can be impressively good at acquiring new skills" (p. 962).

However, the fact that learning occurs in late adulthood does not mean that it is as efficient as in early adulthood. According to Rabbitt (1997), older adults differ from younger adults when performing new tasks, in both quantitative terms (they are slower and less accurate) and qualitative terms (they perseverate and are less likely to modify incorrect responses). The purpose of this thesis is to investigate the validity of this statement by providing comprehensive literature reviews and reporting the results of new experiments focussing on aging and learning. Since learning is such a crucial aspect of human adaptability, it is important for us to determine exactly how learning is affected by aging, and the reasons why it is affected.

The number of older people in the world is also increasing at a constant rate, making it even more important to understand the effects of age on learning. For example, the National Academy Press (2001) stated that the number of people aged 65 and over has increased more than threefold since 1950, from approximately 130 million (4 percent of the global population) to 419 million (6.9 percent of the global population) in 2000. Furthermore, the older population is increasing at a rate of 8 million per year, and this rate is predicted to rise to 24 million per year by 2030. It is also envisaged that the older population will itself grow older. The ‘oldest old’ (aged 80 years and over) are thought to be the fastest-growing sector in the older population at present (National Academy Press, 2001). With a greater number of older adults in our society, and with society constantly changing in terms of knowledge and technology, it will be increasingly important for older adults to adapt to new environments and to learn new skills. Therefore, it is essential to determine whether a relationship exists between aging and learning, and to determine the nature of this relationship. This thesis explores this relationship by discussing general concepts of aging, and presenting the results of two experiments.

Chapter 1 provides a discussion of biological and cognitive changes that occur with aging. For example, as people become older, changes occur in their sensory/perceptual systems, nervous system and brain functioning. These biological changes can lead to cognitive changes, such as the slowing down of information processing and less efficient memory functioning. The changes that occur in these different areas with age may in turn, impact significantly on the learning ability and skill acquisition of older adults.

Chapter 2 deals exclusively with the topic of skill acquisition and transfer. A discussion is provided on the theories of skill acquisition and what they predict in terms of transfer. The chapter also provides a detailed literature review on aging and skill acquisition. Furthermore, the impact of anxiety on skill acquisition is discussed.

In Chapter 3, the reader is introduced to the concept of working memory, and its relationship to learning and skill acquisition. In particular, Baddeley and Hitch's (1974) model of working memory is discussed in great detail, as this model informs the theoretical assumptions underlying the experiments in Chapters 5 and 6. Chapter 4 provides a review of the supporting evidence for the working memory model, as well as the effects of aging on different components of the model. The effect of anxiety on working memory is also examined.

Chapter 4 links together the concepts of aging, skill acquisition, transfer, working memory, and anxiety. In particular, this chapter reviews literature on how factors like working memory and anxiety may affect skill acquisition and transfer in young and older adults. The review focuses on two skills in particular: mental arithmetic (a cognitive skill) and visual numerosity (a cognitive/perceptual skill). These skills were chosen because they are used in the experiments of Chapters 5 and 6.

Chapter 5 introduces the reader to Experiment 1, with a thorough discussion of the experiment's rationale, hypotheses, design, procedure, results and conclusions. In Experiment 1, young and older adults were asked to perform a mental arithmetic task over many trials, as well as complete working memory span measures and anxiety measures. In this way, it was possible to determine whether age differences in skill acquisition and transfer were related to age differences in working memory functioning and anxiety.

Chapter 6 provides a detailed description of Experiment 2. In this experiment, young and old adults performed a visual numerosity task over many trials, and completed several working memory span and anxiety measures. This allowed the effects of working memory and anxiety on performance to be investigated in relation to age differences in skill acquisition and transfer. The results and conclusions of the experiment are also provided in this chapter.

The final chapter provides a comprehensive discussion of the experimental results, the general conclusions that can be derived from the results, and the implications of these results for the aging population and society. In particular, the results display how changes in working memory functioning and anxiety with age may relate to changes in learning ability with age.

Chapter 1: Biological and Cognitive Changes With Aging

Biological Changes

Biological aging is the physical maturation of the body and its organs. The cause of aging is still unknown. However, the physiological changes that occur with aging have been widely studied. These include changes in the senses, the brain and the nervous system. These changes and their impact on the learning ability of older adults are discussed briefly in this chapter.

Sensory Capacity

The five senses of vision, hearing, taste, smell and touch, allow us to be aware of, and interact with, our external environment. Unfortunately, the functioning of our five senses declines with age. This loss of sensory information with age can make it difficult for older adults to understand their environment, to communicate effectively and to live independently (Lemme, 2002). Decreased sensory capacity can also have an effect on the higher-order mental abilities of older adults. This is because there is a decreased amount of sensory input reaching the information-processing system, and the system is less able to respond effectively (Fozard, 1990). The age-related changes in visual and auditory systems can also have effects on working memory for visual and auditory information. Thus, it is important to note that changes in sensory systems can have an impact and can sometimes explain the cognitive changes seen in older adults.

The visual system undergoes several changes with age. Most importantly, changes occur in the eye that limits the amount of light that reaches the retina, including the clouding of the lens (called cataracts) and the decreasing size and reactivity of the pupil (Fozard, 1990). This results in older people needing more illumination to see well. It also leads to impaired visual acuity (the ability to see at a distance and to see details) and impaired contrast sensitivity (the ability to detect and differentiate between light and dark) with age (Fozard, 1990). Other changes that occur with age include the stiffening of the eye lens and the loss of elasticity, which results in farsightedness or the inability to focus on things at close range (Botwinick, 1984). Moreover, the lens of the eye yellows with age, which decreases the sensitivity of the eye to shorter wavelengths of light. As a consequence there is a diminished ability to discriminate between blue, green and violet colours (Botwinick, 1984). In addition, the speed of smooth pursuit and saccadic eye movements decreases significantly with age (Moschner & Baloh, 1994). This has a considerable effect on the visual tracking rate of older adults. However, accuracy in visual tracking is not affected by aging (Moschner & Baloh, 1994). Finally, several studies have found that the useful field of view (i.e., the total area in which visual information can be acquired with one eye fixation) reduces in size with age (Ball, Beard, Roenker, Miller, & Griggs, 1988; Scialfa, Kline, & Lyman, 1987). This suggests that older adults are limited in how much information they can extract during a given fixation. The implication is also that older adults observe smaller sections of a given visual scene, and scan each section more slowly, compared to younger adults.

Hearing also becomes more difficult as people get older. The main problem is that the auditory system becomes less sensitive to high-frequency sounds after the age of 50. As a consequence, older adults have trouble picking up consonants in words since these have higher frequencies than vowels, and often have trouble understanding the speech of women and children (Botwinick, 1984). This problem, called 'presbycusis', is thought to be the leading cause of speech comprehension difficulties in older adults (Schneider, Daneman, Murphy, & See, 2000). Another difficulty is that older adults have a reduced ability to block out background noise, such that it becomes a challenge for them to identify and locate sounds in noisy, crowded settings (United States Congress, 1986). These hearing impairments can be partially explained by accumulated exposure to 'noise pollution' over a lifetime. There is evidence suggesting that presbycusis is more common in industrialised societies (where noise pollution is widespread) compared to traditional societies, and it develops earlier and more severely in men (who generally work in noisier environments) compared to women (Sekuler & Blake, 1987).

Sense of taste does not seem to be significantly affected by aging. A possible reason for this is that taste buds are replaced continually throughout the lifespan (Ivy, MacLeod, Petit, & Markus, 1992). Sense of smell, however, remains relatively intact until the mid-50s when it starts to decline (Ivy et al., 1992). This decline seems to occur at approximately age 55 for men, and age 75 for women (Hayflick, 1994). However, a study by Doty, Shaman, Applebaum, Gilberson, Siksorski and Rosenberg (1984) found that over 50 percent of the population experienced smell perception problems by age 65. This lack of sensitivity to smell can be dangerous for older adults, as it means that they are less likely to detect spoiled foods, smoke or natural gas leaks (Doty et al., 1984).

Finally, age-related changes in the sense of touch have not been studied extensively. However, it seems that a gradual loss in sense of touch does occur with age (Lemme, 2002). This decreased sense of touch can also be dangerous for older adults, as it means they are less likely to detect cuts or injuries on their bodies.

In summary, there is a general reduction in sensory capacity that occurs with age. Since the learning of all skills requires the acquisition of relevant information from the environment through the senses, it is clear that learning will be impaired if the sensory system is impaired. Thus, older adults may find it more difficult to learn motor, perceptual and cognitive skills.

Brain and Nervous System

There are many age-related changes that occur in the brain and nervous system, and these may partially explain the changes in cognitive functioning with age. The most significant change is the loss of brain tissue with age, especially in the cerebral cortex (Ivy et al., 1992). It is thought that about 5 percent of the brain's mass is lost by age 70, 10 percent is lost by age 80, and 20 percent is lost by age 90 (Wisniewski & Terry, 1976). The most affected areas of neuronal loss seem to be the frontal lobes (Ivy et al., 1992), which have been identified by Baddeley (1986) as the areas responsible for the central executive functioning of working memory. The hippocampus, a structure found in the limbic system and involved in memory function, is also thought to deteriorate with age (Mosocitch & Winocur, 1992). However, many studies have found that the neuronal loss in the cortex and the hippocampus is not extensive (Smith, Roberts, Gage, & Tuszynski, 1999). There is also a great deal of variation between individuals of similar ages, such that some individuals over 60 years show no significant neuronal loss, while others do. Therefore other factors, such as the amount of mental activity performed by the individual and the amount of oxygen in the brain, may be responsible for neuronal loss. Finally, there are changes that occur in the circulatory system of the brain that may lead to the breakdown of the blood-brain barrier. This barrier normally protects the brain from potentially harmful substances in the bloodstream (such as amyloid, associated with the development of Alzheimer's Disease). However as the barrier breaks down with age, the brain becomes more vulnerable to infection from these substances (Lemme, 2002).

While there is a general consensus that the loss of nerve cells occurs with age, there is evidence now supporting the notion of brain plasticity. That is, the brain seems capable of modifying its structure and function positively in response to damage or learning experiences (Cotman, 1990). For example, one of the mechanisms that the brain may use to cope with neuronal loss is the redundancy of neurons. It is likely that many neurons (or nerve cells) carry out similar activities so that if one neuron dies or becomes damaged, another can replace it and carry out its function. While this mechanism seems to work well with the minor loss of neurons, it is not as effective with extensive loss of neurons, which often leads to functional loss.

Another compensatory mechanism of the brain is axonal and dendritic sprouting. Both the axon and dendrites are fibres that extend away from the neuronal body – the axon transmits information to other parts of the system while the dendrites receive information from other parts of the system. When nerve cells die, there is evidence to suggest that the surrounding neurons develop or 'sprout' new dendrites and new axons in order to fill the space. In this way, brain function is not lost (Cotman, 1990).

This sprouting mechanism has also been observed in response to environmental enrichment (Turner & Greenough, 1985) and learning (Greenough, 1984, 1988). For example, a number of experiments have found that when rats are moved from a standard laboratory environment to a more exciting environment with novel objects and social contact, the cortex of their brains becomes thicker, and there is more extensive dendritic sprouting (Black, Greenough, Anderson, & Isaacs, 1987; Woodruff-Pak, 1993). It has therefore been suggested that environmental stimulation increases the neuronal connections in the brain whereas decreased stimulation decreases the neuronal connections and functional capacity of the brain (Diamond, 1993).

This increase in neuronal connections seems to occur with learning new tasks as well. For example, in a study by Greenough, Larson and Withers (1985) the researchers trained adult rats for 16 days to reach food using their nonpreferred paw. The training resulted in neuronal changes in the brains of the rats, such that the network of dendrites for the neurons controlling the nonpreferred paw became as complex as that controlling the preferred paw.

More recent studies have suggested that neurons can actually be produced throughout adulthood, especially in response to learning and complex experiences. For example, a study by Gould, Tanapat, McEwen, Fluge and Fuchs (1998) found evidence of neuron production in the hippocampus of several types of monkeys. Similarly, Gould, Reeves, Graziano and Gross (1999) studied the brains of adult macaques (primates) and found the emergence of new neurons in areas of the brain related to learning and memory. To explain this, researchers have proposed that some neocortical neurons (produced prenatally) can be immature and undeveloped, but capable of fast structural changes in response to learning. It is possible that these immature neurons need stimulation from complex experiences to avoid dying (Lemme, 2002).

In summary, the research suggests that the brain's mass and function deteriorates with age. These changes can certainly explain why older adults may experience more difficulty in learning and performing new skills. However, the brain also seems to have compensatory mechanisms for the loss of neurons that can minimise functional impairments in the elderly. There is also evidence that the process of learning actually activates undeveloped neurons. This would support the notion that older adults are capable of learning new skills, although their rate of learning may be slower, and their accuracy may be inferior to that of younger adults.

Conclusion

In conclusion, the biological changes that occur with age involve a reduction in functioning of the physiological systems, which can in turn affect the efficiency of learning with age. This means that older adults may find it more difficult to learn new skills compared to younger adults. Biological changes in the brain can also have an impact on the cognitive functioning of older adults. These cognitive changes are discussed next.

Cognitive Changes

Cognition deals with how people process information from their environment, and how they make sense of this information. There are a number of broad areas within the topic of cognition, including information processing, memory, and learning. These areas of cognition are related to each other, and allow people to live and adapt to their changing environments. The present chapter provides a comprehensive literature review of the areas of information processing and memory. The field of learning and skill acquisition is discussed in more detail in the next chapter.

Information Processing

Human information processing involves retrieving information from the environment and allowing the brain to filter, transform and store this information away. There are several aspects to information processing, including sensory memory, attention, psychomotor speed (Poon, 1985), working memory (Hultsch & Dixon, 1990), and the storage of information in memory systems (Atkinson & Shiffrin, 1968).

Sensory Memory.

When we are first exposed to information from the environment, it is registered by our senses and entered into a sensory memory. Thus, the sensory memory encodes a combination of visual, auditory, taste, tactile and olfactory information from the environment. The rate at which this is done is called the encoding speed. A study by Cerella, Poon and Fozard (1982) investigated age differences in encoding speed by looking at how people processed letters of the alphabet. The researchers found that encoding speed in processing individual letters does slow down with age. This suggests that the amount of visual information that people can deal with simultaneously (called their perceptual span) decreases with age.

Sensory memory has also been studied using backward masking, which involves presenting a target stimulus for a short time (e.g., a letter) followed quickly by a masking stimulus (e.g., a set of lines) that diminishes the distinctiveness of the target. If the interval between the target and the mask is varied, researchers gain an idea of how much the mask disrupts the processing of the target. Many studies have found that the interval between the target and the mask needs to be longer for older people in order for them to identify the target (e.g., Kline & Schieber, 1985).

Attention.

For information to continue being processed beyond the sensory memory stage, we need to pay attention to it. There are three aspects to attention: selectivity, attentional capacity and vigilance (Posner & Boies, 1971).

Attention: Selectivity.

Selectivity involves screening and choosing information for further processing. Although the mechanisms for selectivity are still unclear, it seems that some information is processed automatically whereas other information takes effort. Also, it has been found that novel or unexpected information is more likely to be processed than known or expected information (Cavanaugh, 1997). Researchers have studied selectivity by using tasks such as visual search, spatial cuing and attention switching.

Visual search tasks involve finding a specific target stimulus among a number of distractor stimuli (e.g., finding specific letters from a large array of other letters on a computer screen). This sort of task measures selectivity because it examines the amount of interference caused by nontargets while the subject tries to respond only to the targets (the 'nontarget interference effects'). Most research has found that older adults experience larger amounts of nontarget interference (i.e., they are slower and less accurate at detecting targets when distractors are present) compared to younger adults (Levinoff, Rekkas, & Murtha, 2002; Madden & Langley, 2003; Madden, Pierce, & Allen, 1996; McDowd & Filion, 1992; Plude & Hoyer, 1985, 1986;

Sekuler & Ball, 1986; West, 1999). It has been hypothesised that older adults have more difficulty with visual search tasks because they are less able to inhibit the processing of irrelevant information (Hasher & Zacks, 1988). That is, older adults may process information relating to nontargets as well as targets during a task, and may have difficulty keeping the nontarget information out of their minds. As a consequence, they will be slower in finding the target stimulus in a task. There is substantial support for this inhibition hypothesis (Kane, Hasher, Stoltzfus, Zacks, & Connelly, 1994). In contrast however, Kramer and Atchley (2000) studied 'visual marking' in older adults, which is a process of inhibiting old objects in the visual field so as to direct attention towards new objects. Young and older adults performed a visual search task under three conditions: a full-element baseline condition (with the full number of distractors), a half-element baseline condition (with half the number of distractors), and a gap condition (with half the distractors presented before a 1 second gap, and the remainder of the distractors presented after the gap). The result was that reaction times for the young and older adults in the gap condition were equivalent to their reaction times in the half-element baseline conditions. This suggests that both young and older adults were able to inhibit the old elements during the visual search, and were able to direct their attention towards new elements in the gap condition. However, the older adults were still generally slower at this task than the younger adults. This may be due to changes in perceptual speed and working memory that occur with age. Therefore, it seems that a decline in inhibitory ability does occur with age, but this decline may not be as great as what was previously thought.

The poorer performance of older adults in visual search tasks has also been attributed to their difficulty with feature integration. For example, Plude and

Doussard-Roosevelt (1989) found that older adults were slower than younger adults in searching for targets defined by the conjunction of two features (e.g., form and colour) compared to searching for targets defined by single features (e.g., form only). These results have been replicated by Humphrey and Kramer (1997). The implication of these results is that young and older adults do not differ in their ability to extract feature information (such as colour) about a target stimulus. However, young and older adults do differ in the amount of time they take to put the pieces of information together, such as putting specific colours together with specific letters in a conjunction search. This suggests that older adults are slower at visual search tasks not because they are unable to identify specific pieces of information (or features), but because they take longer to put these pieces of information together (Cavanaugh, 1997).

Other studies focussing on visual search have utilised spatial cuing tasks. With these tasks, a cue stimulus (such as an asterisk) appears on the screen to indicate to the participant where the real target stimulus will be when it is presented shortly afterwards. These tasks were designed to determine whether age differences in visual search are actually due to a decline in spatial localisation ability, or the ability to find the location of a target amongst non-targets (Owsley, Burton-Danner, & Jackson, 2000). Thus, if subjects are told the location of the target stimulus ahead of time, this should eliminate the localisation difficulties of older adults. Indeed, it was found that when subjects are cued about the location of the target stimulus, the age differences disappear (Plude & Doussard-Roosevelt, 1990). However, age differences occur when the spatial cue is ambiguous. For example, if several asterisks appear on the screen but only one provides accurate information about the target location, older adults will take longer to find the target stimulus than younger adults. Similarly, if the validity of a cue (i.e., how accurately it predicts the location of the target) diminishes, older adults become slower in finding the target stimuli compared to younger adults (Madden, 1992). Contextual cuing can also help individuals to locate target stimuli. For example, Chun and Jiang (1998) investigated whether global context (the spatial layout of stimuli in visual search displays) could play a role in facilitating visual search. They asked subjects to perform a visual search task, with half of the visual search display configurations repeated over time, and the targets in these configurations appearing in consistent locations. The results were that targets appearing in repeated configurations were more quickly detected than targets appearing in variable configurations. Thus, it seems that participants learned to recognise the repeated visual configurations over time, and associated certain spatial configurations (context) with specific target locations. In this way, global context guided the spatial attention of subjects towards the target locations.

Finally, the attention-switching task has been used to study selectivity. Hartley and McKenzie (1991) used a visual task of this kind, whereby subjects had to focus on either the central character of a five-character string (the 'narrow attention condition' where the central character was the target), or focus on all five characters in the string (the 'broad attention condition' where the target was one of the peripheral characters). In this task, young and older adults were equally able to switch their attention from one condition to another. In a different study by Madden, Connelly and Pierce (1994), young and older adults were given a choice response task in which 1 of 2 target letters was displayed in 1 of 4 locations on a screen. Older adults were able to switch their attention as quickly as younger adults when the displays contained targets only, but not when the displays contained distractors as well. The ability of older adults to switch visual attention in some conditions has not been replicated in auditory tasks, however. For example, Braune and Wickens (1985) found age differences when subjects were required to switch their attention on verbal tasks, but not when they were required to switch their attention on visual tasks. This may be due to the different rates of change that occur in the visual and auditory systems with age.

Attentional Capacity.

Attentional capacity refers to how much information can be processed at any given time. It is the pool of resources available for information processing to take place. Sometimes information processing occurs automatically and places only a small demand on attentional capacity. Some of these automatic processes are 'prewired' whereas others become automatic through practice and experience (Plude & Doussard-Roosevelt, 1990). In both cases, the information gets processed in our systems without our awareness. At other times, information processing is effortful and relies heavily on attentional capacity. For example, tasks that involve deliberate memory (such as remembering a shopping list) will often require effortful processing.

Divided attention tasks, which measure how well people perform multiple tasks simultaneously, have been used to study attentional capacity. The general finding is that age differences appear on some divided attention tasks but not on others. The reason for this relates to task complexity and practice. Researchers have found that when the tasks of divided-attention are easy, age differences do not occur. However, when tasks of divided-attention are difficult, age differences appear (Crossley & Hiscock, 1992; McDowd & Craik, 1988; Plude, 1990; Whiting & Smith, 1997). That is, older adults are as capable as younger adults at performing multiple tasks simultaneously when the tasks are easy, but not when the tasks are difficult. Researchers have also found that when older adults practice a divided-attention task extensively, they become more capable of performing these tasks. For example, Rogers, Bertus and Gilbert (1994) found that age differences in divided-attention tasks were decreased after subjects were provided with more than 9000 trials of practice. After reviewing the relevant literature, Rogers et al. (1994) proposed that age differences in divided-attention tasks are less likely if subjects are provided with 500 to 11000 practice trials. However, when older adults are provided with less than 300 practice trials, they become less capable than younger adults at performing these tasks.

Several explanations have been offered to explain why older adults have difficulty performing multiple complex tasks or performing multiple tasks with little practice, simultaneously. One explanation is that older adults have a decreased amount of processing resources, and thus a decreased amount of attention that they can apply to a situation (Plude & Hoyer, 1985). However, the processing resource construct has never been clearly defined in empirical research, and certain researchers have found that this explanation cannot account fully for performance impairments with age (Salthouse, 1988, 1991; Salthouse, Kausler, & Saults, 1988). An alternative explanation is that older adults have difficulty with feature integration, especially when the multiple complex tasks are all visual (Plude & Doussard-Roosevelt, 1990). It is suggested that complex tasks require more features to be integrated, and as a consequence this places older adults at a disadvantage. Therefore, age differences on divided-attention tasks are not necessarily due to decreased processing resources, but probably due to difficulty in processing complex tasks (Hartley, 1992).

Attention: Vigilance.

Vigilance (or sustained attention) refers to the ability to maintain attention on a task over a long period of time (Cavanaugh, 1997). The tasks used to research this area have usually involved the monitoring of a display (such as a radar screen) for the appearance of specific targets (such as airplane blips). Researchers then measure sustained attention by looking at the number of targets correctly detected ('vigilance performance') and the decrease in 'hit' rate or correct detections over time ('vigilance decrement'). The small amount of research on this area suggests that vigilance performance decreases with age while vigilance decrement increases with age (Parasuraman, Nestor, & Greenwood, 1989). That is, older adults are not as accurate as younger adults in detecting targets, and they show a greater decline in hit rate over time. These age differences occur even after subjects have practiced the vigilance task over multiple sessions (Parasuraman & Giambra, 1991).

One explanation for vigilance performance decreasing with age is that older adults are less alert during vigilance tasks. For example, Surwillo and Quilter (1964) found a correlation between poorer vigilance performance of older adults and their lower physiological arousal. Giambra and Quilter (1988) supported this finding in their longitudinal follow-up study. Meanwhile, the increased vigilance decrement in older adults may be due to these subjects having more stringent decision criteria when responding to stimuli (Parasuraman et al., 1989). This tendency of older adults to be more conservative in their responses has also been found in other studies employing choice-reaction time tasks (e.g., Wickens, Braune, & Strayer, 1987).

Psychomotor Speed

Psychomotor speed refers to the speed of making a motor movement in response to information from the environment (Cavanaugh, 1997). For example, when driving a car and stopping to avoid colliding with another car, an individual receives information from the environment (i.e., the visual stimulus of the other car) and makes a motor movement in response to this information (i.e., switching the foot to the brake pedal). Psychomotor speed is a measure of how quickly this motor response is made. Psychomotor speed is also a reflection of how efficiently the early aspects of information processing (such as sensory memory and attention) are completed. Psychomotor speed has been studied extensively in the Baltimore Longitudinal Study of Aging, where the same participants were followed up over many years. The results suggest that psychomotor speed (measured by reaction time) declines significantly with age, with men being consistently faster than women across the adult lifespan (Fozard, Vercruyssen, Reynolds, Hancock, & Quilter, 1994). In another study by Cerella (1985), the reaction times of young and older adults were compared in 189 tasks from 35 published studies. A significant effect of age was found on group mean reaction times, suggesting that psychomotor slowing typically occurs with age. Psychomotor speed has also been measured in cross-sectional studies with three types of reaction time tasks: simple reaction, choice reaction, and complex reaction time tasks (Cavanaugh, 1997).

In simple reaction time tasks, subjects are asked to make a simple response (e.g., pressing a button) to a single stimulus (e.g., a light turning on). Researchers can then study two components of reaction time: decision time (the time it takes for the subject to initiate a response from the presentation of the stimulus) and motor time (the time needed to complete the response). Researchers have found that older adults are slower than younger adults in overall reaction time as well as its components (Borkan & Norris, 1980; Salthouse, 1985). However, the age difference is more substantial for decision time than for motor time.

In choice reaction time tasks, subjects are presented with multiple stimuli, and are asked to respond to each stimulus in a different way. For example, a subject may be presented with one of two different coloured lights, and asked to press one of two buttons (left or right) depending on the colour presented. Researchers have found that older adults are slower than younger adults in these choice reaction tasks (Salthouse & Somberg, 1982; Strayer , Wickens & Braune, 1987).

In complex reaction time tasks, subjects are presented with a large number of stimuli, with each stimulus associated with a specific response. It is the subject's task to then respond appropriately to the variety of stimuli presented. Cerella, Poon and Williams (1980) found that older adults are slower than younger adults in these sorts of tasks, and that this age difference increases as the task becomes more difficult. Tasks like visual search also show significant age differences in psychomotor speed (Madden & Allen, 1991).

In summary, research suggests that psychomotor speed declines with age. Many theorists have attributed this decline to changes in the neurons of the brain (Cerella, 1990; Myerson, Hale, Wagstaff, Poon, & Smith, 1990; Salthouse, 1985; Welford, 1988). For example, McClelland, Rumelhart, and the PDP Research Group (1986) proposed a neural network model, where thinking involves making connections between neurons. In order to be an efficient thinker, an individual must make the least number of neuronal connections between the point of information input and the point of information output (where an answer or thought comes out). Since each connection takes up a specific amount of time, the less connections are used, the quicker it is to reach an answer. According to Cerella (1990), when neurons die or become damaged with age, the brain creates bypasses to get to the point of information output. These bypasses result in more neuronal connections being created, so that it takes more time for information to be processed. As a consequence, the psychomotor speed of older adults is slower. Cerella (1990) provided evidence for this hypothesis by using reaction time data to construct mathematical equations that fit the neural network model. That is, reaction times of older adults were found to be consistent with what would be expected of brains undergoing neuronal connection changes.

An alternative model of psychomotor slowing was proposed by Myerson et al. (1990). They suggested that information processing occurs in a series of stages, and that the duration of each stage depends on how much information is available. They also proposed that information is lost during each stage of processing (much like information is lost from a document every time it is photocopied from a copy) making it difficult to interpret the information. Furthermore, this rate of information loss increases with age. Thus, if the duration of each processing stage depends on how much information is available, and if the amount of information decreases with each stage (especially with increasing age), then the natural result is an overall slowing of information processing. Myerson et al. (1990) strengthened their claim by using the model to accurately predict reaction times of older adults from the reaction times of younger adults, irrespective of the task.

According to Salthouse (1996), a decrease in psychomotor speed with age will cause a decline in cognitive functioning because of two mechanisms: the limited time mechanism and the simultaneity mechanism. These mechanisms describe the effect of psychomotor slowing on cognitive processes. The first effect (limited time) is that the execution of early cognitive operations takes longer, which results in less time to perform later operations. Therefore, the later operations are often only partially executed and are less effective as a consequence. The second effect (simultaneity) is that the products of early operations may be lost (through decay or displacement) by the time the later operations are executed. Thus, important information may no longer be available when it is required for processing. As a result of these mechanisms, older adults often perform more poorly than younger adults in cognitive tasks.

Memory

Memory has been researched extensively over the years, and age differences have been found in many studies. Researchers have focussed on many different types of memory, including working memory, short-term memory, long-term memory, episodic memory and semantic memory. .

Working Memory.

Working memory refers to the brain structure that actively processes information at any one time. It does this by holding information and using this information (plus any additional incoming information) to solve problems or make decisions (Craik & Jennings, 1992). Working memory is considered to have a limited capacity such that it can only hold a small amount of information at a time. Therefore, people need to actively use strategies in order to keep information in working memory. One of these strategies is mental rehearsal, which involves either repeating relevant information over and over again, or creating meaningful links between the information to be stored and information already stored in the mind

(Craik & Lockhart, 1972; Kausler, 1985). The creation of meaningful links is a better technique if information is to be stored in working memory for a longer period of time.

There seems to be growing evidence that the capacity of working memory decreases with age (Oberauer & Kliegl, 2001; Salthouse, 1991). For example, Foos (1995) found that when older adults performed a memory span task and mental addition task simultaneously, they performed the tasks more poorly than the younger adults. This suggests that older adults are less able to hold information for the two tasks in working memory, probably due to a smaller capacity of working memory with age. Research by Kausler (1985) and Foos (1989) also found that older adults were less able to mentally rehearse information than younger adults, which results in less information being stored in working memory. A study by Salthouse and Babcock (1991) separated working memory into three separate components: storage, processing and executive functions. The results from 400 adults suggested that age changes in working memory were mostly due to the processing component of tasks. Salthouse (1991) further suggested that the age-related decline in simple speed of processing might also account for this. Other research, however, claims that working memory capacity does not always decline with age. For example, Daneman (1987) found that working memory capacity depends on the type of task given and the type of information to be remembered.

Some research has also been conducted on the effect of practice on working memory. In a study by Campbell and Charness (1990), young, middle-aged and older adults were asked to learn and practice an algorithm for squaring two-digit numbers. The result was that practice dramatically decreased the number of calculation errors made by all age groups. However, older adults made more errors in the working memory components of the task, such as remembering the middle steps of the calculation process. Thus, although practice helped older adults to retrieve arithmetic facts faster (resulting in less calculation errors), practice did not have an effect on how older adults performed the working memory components of the task. A more detailed discussion of the relationship between working memory and practice is presented in Chapter 3 of this thesis.

Short-Term Memory.

According to Cavanaugh (1997), short-term memory refers to an individual's ability to remember large amounts of information for relatively short amounts of time (e.g., from a few seconds to a few hours). Researchers have studied short-term memory by giving subjects certain tasks (e.g., learning a list of words) and then asking them to recall or recognise items from the task. In memory recall tests, subjects are asked to remember items without help from cues or prompts, whereas in recognition tests, subjects are asked to remember and pick out previously learned items from a new set of items. Hundreds of short-term recall studies have found that older adults perform worse than younger adults, even when the rate of item presentation is slowed down or when cues or prompts are given (e.g., Bleecker, Bolla-Wilson & Heller, 1985; Craik & McDowd, 1987; Poon, 1985). According to Verhaeghen, Marcoen and Goossens (1993), about 80% or more of young adults (aged in their 20s) will outperform their older adult counterparts (aged in their 70s) in a sample group. However these age differences are greatly reduced when recognition tests are used instead of recall tests. Moreover, recognition tests seem to improve the performance of all age groups involved (Poon, 1985).

One explanation of the age differences in short-term memory abilities is that older adults are less able to use mental study strategies such as repetition, imagery, grouping items into categories, or associating items with previously learned information. Several studies have investigated the performance of older adults when they are specifically asked to use mental study strategies when learning new information (e.g., Verhaeghen & Kliegl, 2000; Verhaeghen et al., 1993). The results from these studies are that although older adults improve significantly in their performances, the improvements are not enough to eliminate age differences. Furthermore, when young and older adults are taught to use different strategies for learning new information, older adults are not as able to identify the most effective strategy compared to younger adults, and older adults are less likely to utilise the effective strategy for subsequent learning compared to younger adults (Brigham & Pressley, 1988). Verhaeghen and Marcoen (1994) suggested that older adults might be less able to use mental study strategies because of age-related changes in their speed of processing and associative memory. Therefore older adults are disadvantaged when they are required to learn disorganised information and recall it later.

Long-Term Memory.

Long-term memory involves the storing of information for long periods of time, from a few hours to many years (Poon, 1985). This information often includes important life events, the meaning of words, arithmetic facts and so on. Research on long-term memory is difficult because information from a person's past cannot always be verified. Moreover, a person may not be able to remember information from the past because they never learned the information in the first place

(Cavanaugh, 1997). However, researchers have been able to overcome these barriers by studying two types of long-term memory: knowledge base and autobiographical memory.

The term 'knowledge base' refers to knowledge about public events (e.g., significant historical events) that are assumed to be available to everyone. Most studies use questionnaires to determine the knowledge base of subjects. The results of these studies have found negligible age differences in how well people remember public events (e.g., Lachman & Lachman, 1980; Perlmutter, Metzger, Miller & Nezworski, 1980). In a study by Camp (1989), an alternative method was used whereby subjects had to combine pieces of information in their long-term memories in order to answer inference questions. For example, subjects might be asked, "What horror movie character would want to avoid the Lone Ranger?" (Cavanaugh, 1997, p. 195). The correct answer for this question is the werewolf, since it can only be killed by silver bullets, which the Lone Ranger possesses. It seems that older adults are just as good as, and often better at answering these sorts of questions than younger adults are. This suggests that there are no age differences in long-term memory, and that long-term memory may in fact improve with age.

Autobiographical memory involves remembering information and events from our personal lives. A study by Bahrick, Bahrick and Wittlinger (1975) looked at the ability of subjects aged 17 to 74 years to remember the names and faces of their highschool classmates. The results indicated that adults in their 70s were still able to recognise 70% of their classmate's names, even 48 years after graduation. Another study by Coleman, Dwyer and Casey (1994) looked at the ability of middle-aged adults to remember personal childhood characteristics from up to 40 years earlier. Ninety-one participants of approximately 50 years of age were asked to recall childhood characteristics such as body size (e.g., weight and height) and maturational events (e.g., menarche) in a self-administered questionnaire. The researchers found that the participants were exceptionally accurate about their personal information and history. Thus, it seems that long-term memory stays fairly intact with age.

Episodic Memory.

Episodic memory involves remembering information that was learned at a specific point in time (Cavanaugh, 1997). Examples include learning course material for an exam, or memorizing a speech for a play. Most memory tests that are used in research rely on episodic memory, since they ask subjects to remember information (such as word lists or numbers) that were presented within the time and setting of the experiment. In this sense, the time frame during which the information was learned can be referred to as the 'episode'. Other tests of episodic memory may ask subjects to remember personal events, such as what they did two days ago, or what they ate for dinner last night (Whitbourne, 1996).

There is overwhelming evidence that older adults perform less well than younger adults on tests of episodic memory (Denney & Larsen, 1994). A study by Verhaeghen and Marcoen (1993) analysed 122 cross-sectional studies on episodic memory and found evidence of significant age differences, with age accounting for about 83% of the variance in performance. The significant age differences in episodic memory have also been found when the information to be remembered is meaningful prose, text, stories or sentences (Tomer, Larrabee, & Crook, 1994; Zabrucky & Moore, 1994). Furthermore, the substantial age difference in episodic memory appears in longitudinal research as well as cross-sectional research (Small, Dixon, Hultsch, & Hertzog, 1999; Zelinski, Gilewski, & Schaie, 1993).

However, the age differences in episodic memory are greatly reduced when contextual information is provided at the encoding stage (e.g., providing subjects with strategy instructions) or at the retrieval stage (e.g., providing subjects with cues and prompts). In a study by Craik, Byrd and Swanson (1987), subjects were asked to learn a word list either with or without a descriptive phrase (e.g., a body of water, POND). The researchers found that age differences were most reduced when cues were provided at both the encoding and retrieval phases. A similar result was found by Shaw and Craik (1989).

A component of episodic memory is memory for the future, called 'prospective memory'. This memory is similar to a mental 'to do' list, where the individual must remember to feed the dog, put out the garbage, and so on (Whitbourne, 1996). Studies on prospective memory have found that older adults perform more poorly than younger adults, although this age effect is not as substantial as that found in retrospective episodic memory (Mantyla, 1994; Mastroianni, Panza, Solfrizzi, Nardo, Torres, Resta & Capurso, 1996; Maylor, 1993).

Semantic Memory.

Semantic memory involves remembering word meanings, concepts and facts that have been learned over a lifetime, and that are not related to specific occurrences in time (Cavanaugh, 1997). Examples include remembering word definitions for a crossword puzzle, understanding what a lecturer is saying, or remembering general knowledge information in 'Trivial Pursuit'. In contrast to episodic memory, semantic memory seems to stay relatively intact with age (Light, 1992; Light & Burke, 1988). For example, the general knowledge questions in IQ tests are usually answered equally well by older adults as by younger adults (Salthouse, 1982, 1991) and the ability to use language (which relies somewhat on semantic memory) shows little decline until adults reach their seventies or eighties (Salthouse, 1982; Wingfield, Wayland & Stine, 1992). However, some aspects of semantic memory have been shown to deteriorate with age. For example, word-finding difficulty increases with age (Burke, MacKay, Worthley & Wade, 1991), and the ability to retrieve names becomes impaired with age (Cohen & Faulkner, 1986; Maylor, 1990). It is still unclear why these aspects of semantic memory are affected by age, while others are not (Craik, 2000).

Conclusions

Overall, the research suggests that some aspects of cognitive functioning decline with age whereas other aspects remain intact. In terms of information processing, it seems that older adults are slower than younger adults at encoding sensory information, they are less able to attend to relevant information, they have difficulty performing multiple complex tasks, they are not as accurate as younger adults in detecting targets, and they appear to have slower psychomotor speeds compared to younger adults. However, older adults seem to attend to relevant information as well as younger adults when they are cued about the stimulus location, they can switch their attention between tasks if the tasks are simple, and they can improve when performing two concurrent tasks if they are given extensive practice. Therefore, some aspects of information processing do seem to remain intact with age.

Research on aging and memory has also provided mixed results. For example, some studies have found that working memory capacity decreases with age, whereas other studies have found that working memory span depends on the type of task given. Research on short-term memory has revealed significant age differences in recall test performance (with younger adults performing better than older adults), but minimal age differences in recognition test performance. Furthermore, research on long-term memory has found that this memory is unaffected by age. In terms of episodic and semantic memory, research has found that episodic memory declines with age while many aspects of semantic memory remain intact with age. Therefore, it seems that while some types of memory become impaired with age, other types of memory remain unaffected.

In summary, it is clear that aging does not involve a simple inevitable decline in cognitive functioning. On the contrary, there are many aspects of information processing and memory that remain intact, and even improve, with aging. This is an important point to consider, because many aspects of cognition that remain intact with age can actually help older adults to learn new information and to acquire new skills. The extent to which older adults can learn and acquire new skills is considered in the next chapter.

Chapter 2: Skill Acquisition and Transfer

The topics of skill acquisition, transfer and learning are central to this thesis, and to the experiments that have been conducted and described in Chapters 5 and 6. This chapter deals with these topics in detail and, in particular, focuses on the power law of practice, the stages of learning, theories of skill acquisition (i.e., Anderson's ACT* Theory and Logan's Instance Theory), the transfer of skill, the effects of anxiety on skill acquisition, and the effects of aging on all aspects of skill acquisition and transfer.

Skill Acquisition

The term 'skill' has been given many definitions throughout the years. Proctor and Dutta (1995) describe 'skill' as "... goal-directed, well-organized behavior that is acquired through practice and performed with economy of effort" (p. 18). For an individual to acquire a skill, he/she must undergo a process that causes long-standing changes in their behaviour and is based on experience (Zimbardo & Gerrig, 1988). Therefore, it is assumed that learning has occurred if changes in an individual's behaviour occur consistently over different occasions, if their learning can be observed in their overt behaviour (even though the process of learning occurs internally), and if they have undergone extensive practice or experience to acquire the new behaviour (Tomporowski, 2003).

The Power Law of Practice

Newell and Rosenbloom (1981) reviewed numerous research studies on skill acquisition, and found that with most skills, performance improves with practice. Moreover, they found that when performance is plotted against practice on a graph, it often follows a power function of the form $RT = a + bN^{-C}$, where RT is the response time, N is the number of practice trials, *a* represents the asymptotic performance, *b* represents the total amount of speed-up possible, and *c* represents the rate of learning (Carlson, 1999). Newell and Rosenbloom (1981) wrote:

> There exists a ubiquitous quantitative law of practice: it appears to follow a power law; that is, plotting the logarithm of the time to perform a task against the logarithm of the trial number always yields a straight line, more or less. We shall refer to this law as the *log-log linear learning law* or the *power law of practice* (p.2).

The power law of practice describes the changes that occur in skill learning. That is, early on in training there are dramatic gains in performance, but with additional practice the amount of improvement gradually decreases. Performance ultimately reaches an endpoint, or *asymptote*, where only minimal improvement is possible, and only if great amounts of energy and time are available (Tomporowski, 2003). Thus, when individuals learn a skill for the first time, they improve extensively with practice to begin with, but as they become more skilled their rate of improvement slows down (Tomporowski, 2003). This power law of learning has been found with motor tasks such as the rolling of cigars (Crossman, 1959), perceptual-motor tasks such as mirror-drawing (Snyder & Pronko, 1952), perceptual learning tasks such as visual search for targets (Neisser, Novick, & Lazar, 1963) and cognitive tasks such as alphabet arithmetic (Logan, 1992), the solving of electronic circuit problems (Carlson, Khoo, Yaure & Schneider, 1990), and writing books (Ohlsson, 1992).

However, not all researchers accept the 'ubiquity' of the power law in skill acquisition research (Lane, 1987). For example, Shephard and Lewis (1950, cited in Lane, 1987) stated, " ... there is no single 'generalized' learning function, no 'true' curve of learning and performance " (p. 34). Similarly, Conway and Schultz (1959, cited in Lane, 1987) reported, " ... there is no such thing as a fundamental law of progress ... No particular slope is universal, and probably there is not even a common model " (p. 34). Moreover, a recent study by Delaney, Reder, Staszewski and Ritter (1998) found that curves based on the strategy use of participants provided better fits to the data compared to power law curves.

As a consequence, some researchers have used other functions, such as the exponential growth equation or 'negative exponential', to explain their research data (Lane, 1987). The exponential equation has the form $RT = a + be^{-cN}$, where 'e' is the natural logarithmic base. It has similarities with the power equation in its visual appearance and its negative acceleration. However, its initial acceleration is usually more rapid than that of a power curve, and so results in a much steeper slope (Lane, 1987). According to Lane (1987), "... There is nearly as large a literature supporting the negative exponential as the common form of skill growth as that ... cited for the power function " (p. 38). For example, Hull (1951) described the growth of habit strength with an exponential equation, as did Wickelgren (1974) for habit strength decay. Moreover, the exponential equation was found to be a perfect fit for conventional perceptual-motor tasks (Digman, 1959; Noble, Salazar, Skelley, & Wilkerson, 1979).

Therefore, it seems that data can often be described by both an exponential curve and a power curve, making it difficult to determine which curve is the 'best' fit. As Lane (1987) pointed out, "...Much of the data reported in support of the power law also support the exponential as a satisfactory descriptive function" (p. 38). For example, Mazur and Hastie (1978) fitted 56 curves on perceptual-motor skill data, and found that in most cases, the power function was only marginally better at fitting the data than the exponential function, while in some cases the exponential function was actually better at fitting the data than the power function. Similarly, Hackett (1974, cited in Towill, 1976) fitted 88 curves on industrial task data, and found that the time constant model (a version of the exponential function) fitted the data as well as and sometimes better than any other function (presumably including the power function).

According to Lane (1987) it is likely that the power curve is a better fit under some learning conditions while the exponential curve is better under different learning conditions. To investigate the conditions appropriate for each curve, Heathcote, Brown and Mewhort (2000) fitted power functions and exponential functions to 40 sets of learning data from 24 different experiments. Their results indicated that power functions provided better fits when learning data was averaged, while exponential functions provided better fits when learning data was unaveraged. Carlson (1999) also proposed that the exponential function may provide a better fit for tasks in which performance improvements are better described by parameters other than speed (e.g., parameters such as smoothness of performance, timing or rhythmicity of performance). Thus, it seems that for certain conditions, exponential functions may provide a better fit to data than power functions. To determine which function provided a better fit for the data in the experiments reported in Chapters 5 and 6, both types of functions were fitted to the data sets, and the amount of variance was calculated for each function. The two measures of variance used were R^2 and the root mean squared deviation (RMSD). The function with the highest R^2 value and the lowest RMSD value was then considered to be the one providing the better fit.

Stages of Learning

When learning a skill, the individual's performance changes from a slow and effortful performance to a rapid and effortless one. According to Fitts and Posner (1967), this shift in performance occurs over three phases. In the first phase (the 'cognitive' stage), the individual uses strategies from previously learned tasks to develop strategies for performing the present task. Performance during this phase relies on the person's attentional resources, and is usually slow and prone to errors. In the second phase (the 'associative' stage), aspects of the previously learned strategies that are appropriate to the present task are strengthened through positive feedback, while those aspects that are inappropriate are weakened. In the third phase (the 'autonomous' stage), the components of the performance strategy become more autonomous and require less cognitive control. Thus, the individual's performance becomes faster and more efficient, although the rate of improvement decreases (Speelman & Maybery, 1998).

According to Shiffrin and Schneider (1977), the three phases of skill acquisition are associated with a shift from controlled processing to automatic processing. Controlled processing is seen as slow, error-prone, intentional, effortful and available to conscious awareness; whereas automatic processing is seen as fast, error-free, occurring without intention, effortless and unavailable to conscious awareness. Shiffrin and Schneider suggest that controlled processing is used in phase one of skill acquisition; a mixture of controlled and automatic processing is used in phase two; and automatic processing only is used in phase three. In other words, skill acquisition is seen as the acquisition of automaticity in that skill (Logan, 1985).

Although their conceptualisation remains very popular today, Shiffrin and Schneider (1977) failed to explain how the transition from controlled processing to automatic processing actually occurred. That is, they failed to describe the mechanism responsible for the transition. Several theories of skill acquisition have since been proposed in an attempt to describe this mechanism. The two main theories are Anderson's ACT* Theory (1982, 1983, 1987) and Logan's Instance Theory (1988).

Anderson's ACT Theory*

Anderson's ACT* Theory (Anderson, 1982, 1983, 1987) describes in more detail the three phases of skill acquisition proposed by Fitts and Posner (1967). In the first phase ('cognitive' phase), the subject obtains facts, statements and/or instructions about the task, known as declarative knowledge. The individual is consciously aware of these facts, and can verbally describe them to others. The facts are organized into 'chunks' and stored in working memory (Speelman & Maybery, 1998).

In the second stage ('associative' stage), the declarative knowledge is compiled into procedural knowledge. Procedural knowledge is knowledge about the task that the individual displays in his/her behaviour, without being consciously aware of it (Anderson & Lebiere, 1998). Since procedural knowledge is learned without conscious awareness, this type of learning is considered by many researchers to be a form of "implicit" learning (eg., Ashby, Alfonso-Reese, Turken, & Waldron, 1998; Cohen & Squire, 1980; Shanks & St John, 1994; Squire, 1986). A process called 'proceduralisation' is responsible for converting the declarative knowledge into production rules. Production rules are if-then statements that link certain stimulus conditions with appropriate cognitive or physical actions. For example, a trainee doctor may learn that if a patient suffers from symptoms A and B then diagnosis X should be considered. When declarative knowledge is transformed into production rules, the information relating to the task is no longer verbally rehearsed in working memory and no longer accessible for verbal reporting. That is, individuals are unable to report what productions they are using mentally. They can report on the contents of their working memory, but not on the productions that lead to the formation of these contents. This lack of verbal rehearsal and access means that the load on working memory is decreased, making performance faster and more accurate.

The process of 'composition' that occurs during the associative stage also speeds up performance. In composition, several productions are combined into a single production. However, productions can only be collapsed if they follow a consistent sequence and relate to the same goal. The resulting production achieves the same goal as the sequence, but does so in fewer steps. If it is assumed that each processing step takes up one unit of time, then it is clear that the final production (which has less steps) results in quicker processing and faster performance than the initial productions. Thus, an overall speed-up in performance is achieved.

The third stage of Anderson's ACT* Theory ('autonomous' stage) involves the strengthening of productions. When a production is applied successfully it gains strength; and when it is applied unsuccessfully (or is not applied at all), it loses strength. Therefore, strengthening depends strongly on feedback. The strength of a production is very important because it determines how rapidly the production is then applied (i.e., the stronger a production, the faster it is applied). Therefore, strengthening brings about a speed-up in performance, but not to the same extent as proceduralisation or composition does. The strengthening process defines the rate of skill acquisition as the asymptote of the power-function is approached (Anderson, 1983).

The ACT* theory (Anderson, 1982) also describes how individuals acquire general and specific skills. General skills are those that can be used with any stimuli in a particular domain, whereas specific skills can only be used with certain stimuli in that domain. According to Anderson (1982), a production is initially item-general, in that it can be applied to any item in a particular domain (e.g., how to spell a word). However, after repeatedly encountering information about a certain item (e.g., how to spell the word 'cat'), the specific information relating to this item is incorporated into new productions through the process of composition. Although item-specific productions are then created, the original item-general productions are still available. However, when more than one production can be applied to the same specific item, a competition occurs between productions and the most specific production is then used (Anderson, 1982).

In summary, Anderson's ACT* theory proposes that performance becomes automatic when declarative knowledge is compiled into procedural knowledge. With practice, multiple productions are compiled into single productions that are efficient, specific, and faster than the collection of multiple productions. These productions are no longer accessible for verbal reporting. The result is that performance on a task speeds up and places less demands on working memory.

To determine the validity of the ACT* theory, Pirolli and Anderson (1985) analysed the verbal protocols of three subjects learning a recursive programming task. They were then able to develop computer simulations based on these verbal protocols, and found that ACT* theory could accurately describe the processes involved when learning the skill.

Since the conception of ACT* in 1982, Anderson has made some changes to his theory, although the basic principles for skill acquisition have remained the same. The updated theory, called ACT-R (Anderson & Lebiere, 1998), still makes a distinction between declarative knowledge and procedural knowledge. The basic units of each type of knowledge (i.e., chunks in declarative knowledge, and production rules in procedural knowledge) are regarded as the 'symbolic' parts of the system. However, one important aspect of ACT-R is that sub-symbolic parameters are associated with each symbolic construct (i.e., with each chunk or production). The purpose of these sub-symbolic parameters is to monitor the general usefulness of the symbolic information, based on its past usefulness. For example, a chunk in declarative memory is activated based on the probability that it is needed in the current context. Each time that the chunk is used, its probability of activation increases. In a similar fashion, production rules are selected based on their expected gain, which is calculated from the probability of reaching the goal and the expected costs of reaching the goal. The probability of reaching the goal is based on the past ratio between successes and failures. Therefore, the sub-symbolic parameters allow the past usefulness of chunks and productions to affect whether they will be selected again in the present.

Another important aspect of ACT-R is that it functions in real-time. According to Ritter, Shiskowski and Van Rooy (2003), " each covert step of cognition (production firing, retrieval from declarative memory) or overt action (mouse-click, moving attention) has latencies associated with it that are based on psychological theories and data " (p. 3). For example, Anderson (1996) collected data on how adults scanned mathematical equations, and how much time they spent on each symbol in the equation. By determining the productions necessary for each step in the equations, Anderson found that the time required to fire a production was about 100 milliseconds. According to Ritter et al. (2003), it is also possible to calculate the time that subjects take in scanning parts of a computer screen, by using Fitts' law. This law states that the time needed to make a rapid movement depends on the distance of movement and the size of the target (which determines how precise the movement needs to be). This law can be expressed mathematically as $MT = a + b\log2(2A/W)$ where MT is the movement time, A is the distance of movement to the target, W is the width of the target, and a, b represent the regression coefficients (Amento, Brooks, Harley, & McGee, 1996). This real-time cognitive timing in ACT-R means that researchers can obtain more accurate information about how the perceptual and motor systems of the body function during learning.

Thus, the ACT-R model (Anderson & Lebiere, 1998) is more developed than ACT* (Anderson, 1982). However, the experiments presented in this thesis (see Chapters 5 and 6) are concerned with the basic concepts of the model, rather than the more recent and more advanced details. Therefore, the simpler ACT* model has been used to interpret the data in the experiments.

Logan's Instance Theory

Logan (1988) proposed a memory-based theory to account for the development of automaticity with practice. According to his theory, initial performance relies on the use of a general problem-solving algorithm that is appropriate for the particular task. Each time the algorithm produces a successful outcome, the solution is remembered and stored in memory as an 'instance'. Performance of the task then involves either the execution of the algorithm, or the retrieval of past solutions stored as instances. According to Logan (1988), a race occurs between the execution of the algorithm and the retrieval of an instance, so that whichever one is fastest controls the individual's performance. Since the number of stored instances increases with practice, the likelihood of retrieving an instance in less time than executing the algorithm also increases. Eventually, performance becomes completely dependent on the stored instances, since the retrieval of instances becomes consistently faster than the execution of a general algorithm. At this point, performance becomes automatic and fast, and results in a speed-up in the power-function (Logan, 1988).

Logan's theory also explains the negative acceleration that occurs in the power function. While an increased number of instances in memory increases the likelihood that one of these instances will be extremely fast, it also decreases the likelihood that a new instance will be even faster. Therefore, as the speed of the fastest instance increases, the probability of storing an even faster instance decreases, thus reducing the amount of improvement in performance. Eventually a point is reached where no further improvement is possible, and this point corresponds to the asymptote of the power function (Newell & Rosenbloom, 1981).

According to Speelman and Maybery (1998), Logan's theory is actually similar to Anderson's ACT* theory. That is, although the two theories suggest different mechanisms for automaticity in performance, they both make similar predictions about performance. For example, both theories propose that initially performance is slow, deliberate and dependent on a general algorithm, while with practice performance becomes reliant on a single-step process and faster as a result. Thus, both theories explain automaticity in terms of retrieving a specific solution from memory (an item-specific production for ACT* theory, and an instance for Logan's theory) in response to particular stimulus conditions. For this reason, Logan

(1992) actually regarded both the ACT* theory and the instance theory as memory-based explanations of automaticity.

Age and Skill Acquisition

Research has been conducted on how older adults acquire skills compared to younger adults. The types of skills that have been researched include motor skills, perceptual skills, cognitive skills and implicit skills.

Motor Skills

Motor skills are those in which voluntary body or limb movements are needed to achieve a goal (Magill, 1998). However, these physical movements are usually coordinated with the perception of stimuli, and therefore these skills are often called perceptual-motor skills. Examples of motor or perceptual-motor skills include driving a car, using a typewriter, hitting a baseball or playing a musical instrument (Kausler, 1994).

Several studies have confirmed that older adults are slower than younger adults at performing motor or perceptual-motor skills. For example, when individuals are asked to make a simple motor movement (e.g., press a button) in response to a single stimulus (e.g., onset of a tone), the speed of response decreases as the age of the individual increases from early adulthood to late adulthood (Kausler, 1994). A study by Borkan and Norris (1980) found that the correlation coefficient of this age-speed relationship was .29 for 687 individuals aged from 17 to 102 years. Similarly, Robertson-Tchabo and Arenberg (1976) found a correlation coefficient of .41 for 90 individuals aged from 20 to 80 years. Such results have also been found in choice-reaction tasks, where individuals must make a particular motor response for one kind of stimulus, and a different motor response for another kind of stimulus (Borkan & Norris, 1980; Robertson-Tchabo & Arenberg, 1976). Older adults are also slower than younger adults in a variety of real-world motor tasks, including writing words and digits (Birren & Botwinick, 1951), sorting cards (Botwinick & Birren, 1965), and dialing a telephone (Potvin, Tourtellotte, Pew, Albers, Henderson, & Snyder, 1973).

Laboratory tasks have often tried to imitate real-world motor tasks by asking individuals to make a movement of some specified distance, amplitude, or direction (Kausler, 1994). In one study, Anshel (1978) asked young and older adults to move a cylinder 80° from a resting point. The results indicated that older adults were slower than younger adults at this task, and on average made more errors. However, the accuracy of older adults improved as much as it did for younger adults over the 20 trials, suggesting that older adults were just as able to learn the task as younger adults. In another study by Marshall, Elias and Wright (1985), older adults were less accurate than younger adults when judging hand movements compared to an established criterion movement. However, accuracy for all adults increased when the difference between the noncriterion movement and the criterion movement increased. A study by Warabi, Noda and Kato (1986) found that when older adults made rapid movements they made more aiming errors, and were less likely to correct these errors, than younger adults. Similarly, Toole, Pyne and McTaraney (1984) asked young, middle-aged, and older adults to move a linear slide over different distances and to reproduce the series of movements. Although no age differences were found for the reproduction of a short series of movements (e.g., 1, 3, or 6 separate movements), age differences were found for the reproduction of longer series of movements (e.g., 9 or 12 movements). Finally, Roy, Weir, Desjardins-

Denault and Winchester (1999) investigated how well young and older adults could point to or grasp two disks (of different sizes) over two different amplitudes. The results were that both age groups were able to perform the tasks. However, the older adults generally moved more slowly and had longer acceleration and deceleration times compared to the younger adults.

Other research studies have employed tasks that use continuous responses, where the individual coordinates his/her motor movements in response to rapidly changing visual stimuli (Kausler, 1994). One study by Wright and Payne (1985) required young and older adults to track a silver target as it moved clockwise through a star-shaped pathway. The researchers recorded the individuals' time on target for consecutive 30-second periods. The results indicated that elderly subjects spent less time on target and improved at a slower rate compared to their younger counterparts. This age-related deficit increased with practice. In another study by Swanson and Lee (1992), young and older adults were required to perform three movements to a barrier in a specified time. Therefore, the goal of this task was not to move as quickly as possible, but to time each movement as accurately as possible. The results indicated that both age groups improved in accuracy with practice, although young adults improved to a greater degree than older adults. Since both age groups were given feedback about their accuracy during the course of the experiment, this suggests that older adults were just as capable as younger adults in processing feedback to improve performance. The higher accuracy of younger adults overall may simply reflect the better timing ability of that age group (Kausler, 1994). A more recent study by Jagacinski, Liao and Fayyad (1995) studied motor skill acquisition by asking young and older adults to manually track sinusoidal input signals. The results from this study were that older adults lagged behind the target to a greater extent, they made considerably smaller movements, and their movements were slower compared to younger adults. This supports the theory that aging is associated with generalized slowing. On the other hand, a study by Durkin, Prescott, Furchtgott, Cantor and Powell (1995) investigated the ability of young and older adults to learn a pursuit rotor task and a mirror-reading task. For both of these tasks, the investigators found that the initial and terminal reaction times for the older adults were indeed slower than the reaction times for the younger adults. However, the decrease in reaction times that occurred with practice was approximately the same for both age groups. This suggests that while the performance of a motor skill (i.e., the reaction time) is often affected by age, the acquisition of a skill (in terms of faster performance with practice) can remain unaffected by age.

Finally, several motor-skill studies have found that older adults are capable of learning word-processing and computing skills, even though they may be slower than younger adults. For example, Elias, Elias, Robbins and Gage (1987) trained young, middle-aged and older adults in word processing using a commercial training program. The results were that all subjects acquired the basic skills of word-processing. However, the older adults took longer to complete the training. Similarly, studies by Czaja, Hammond, Blascovitch and Swede (1989) and Czaja and Sharit (1993) found that when young and older adults were trained to use computer software, the older adults were slower compared to the younger adults. However, the finding that older adults made more errors than younger adults suggests that the older group did not learn the skill as well as the younger group. On the other hand, Zandri and Charness (1989) found that while older adults took twice as long as younger adults to learn how to use computer software, the older adults achieved approximately the same performance level (in terms of accuracy) as the younger adults. Therefore, it seems that older adults are capable of performing some tasks as accurately as younger adults, even though the tasks may take them longer to acquire.

Overall then, the research that has been conducted on aging and motor skill acquisition suggests that older adults perform motor tasks more slowly than younger adults. This general slowing could be associated with changes in the musculoskeletal system that occurs with age. For example, from about age 40 to age 70 years, there is an approximate muscle loss of 10 to 20 percent, while after age 70 years the muscle loss increases to approximately 40 percent (McArdle, Katch & Katch, 1991). This decline in muscle tissue has been shown to relate to a decrease in muscle strength (Kallman, Plato, & Tobin, 1990; Phillips, Bruce, Newton, & Woledge, 1992), which can in turn make it difficult for older adults to perform certain motor skills. Changes in the brain and neurons can also make it difficult for signals to be efficiently transmitted to and from the nerves and muscles. For example, Wisniewski and Terry (1976) reported that about 5 percent of the brain's mass is lost by age 70, 10 percent is lost by age 80, and 20 percent is lost by age 90. However, the plasticity that occurs in the brain seems to allow older adults to learn new skills (Cotman, 1990). The research on motor skills has indeed shown that older adults can acquire motor skills, as indicated by their improvements in performance with practice. However, it is unclear at this stage whether older adults can perform these tasks as accurately as younger adults, since the research in this area has provided mixed results.

Perceptual Skills

Perceptual learning refers to any alteration of perception that can be attributed to learning. Examples of perceptual skills include learning to read maps, learning to identify slides under a microscope, and learning to identify a piece of music

(Tomporowski, 2003). The acquisition of a novel perceptual skill has been investigated by Hashtroudi, Chrosniak, and Schwartz (1991; Experiment 2). In their experiment, young and older adults were asked to identify words using word fragments. While younger adults were able to improve on this task with practice, older adults did not show any improvements with practice. Similar results were found in an earlier study by Kline, Culler and Sucec (1977).

Other research on perceptual learning has focused on the area of target detection, whereby subjects are required to detect whether a brief target stimulus is present or not. Salthouse and Somberg (1982) asked young and older adults to detect a target stimulus of 5 dots within an array of 60 dots, over a large number of trials. Although the detection accuracy of both young and older adults improved with practice, the performance of the older adults was always inferior to that of the younger adults.

Similar results have been found in stimulus discrimination research, in which subjects are asked to discriminate between stimuli and make different responses accordingly. In a study by Fozard, Thomas and Waugh (1976), 123 participants aged between 25 and 79 years old were given a choice-reaction-time task in which they had to make a certain response for one stimulus (a red light) and another response for a different stimulus (a green light). While both the young and older adults became faster at discriminating with practice, the performance of the younger adults was always superior to that of the older adults, even at the end of practice. The slower performance of older adults may be due to a decrease in psychomotor speed with age, and an increase in variability of decision-making with age. In a different study, by Salthouse and Somberg (1982), young and older adults were presented with two visual arrays simultaneously for 400msec. Participants were asked to determine the presence or absence of a target stimulus in each array, and to make responses accordingly. The results were that accuracy scores increased with practice for both age groups, indicating that older adults were able to learn this visual discrimination task. However, at the end of the trials, the accuracy level for older adults still remained much lower than that for younger adults. On the other hand, a similar study by Swearer and Kane (1996) found different results. In their experiment, young and older adults were presented with three stimulus squares on a computer screen, with one of the squares slightly above the center of the screen, and two of the squares slightly below the center. The upper square (sample) was identical to one of the lower squares, and the other lower square was perceptually different from the identical squares. Participants were required to indicate which of the two lower squares was identical to the upper square in each trial, by pushing different keys on a keyboard. The results of this study were that accuracy was not affected by age (which contradicts the results of the Salthouse and Somberg study) but reaction time was affected by age, with younger adults being significantly faster than older adults.

Other perceptual learning studies (e.g., Gaylord & Marsh, 1975; Shepard & Metzler, 1971) have investigated the ability of different age groups to rotate figures mentally. In such studies, participants are presented with a target visual pattern or configuration, followed by a second pattern or configuration. The individual is then required to determine whether the second pattern is a rotated version of the target pattern or not. These studies have found that older adults are much slower than younger adults in performing these mental rotations. This age deficit probably occurs because mental rotation involves manipulating visual information in working memory (which involves cognitive processing), and older adults probably have less processing resources in working memory compared to younger adults (as discussed in Chapter 1).

Research has also explored the area of pattern-recognition learning, whereby subjects are required to identify or recognize a collection of stimulus elements after many practice trials (Kausler, 1994). In a study by Hertzog, Williams, and Walsh (1976), participants were asked to identify letters of the alphabet as patterns to be recognised. The method of 'backward masking' was used, whereby each letter was briefly presented, followed by a brief interval, and followed by a masking stimulus to inhibit further processing of the target letter. The results were that older adults were always slower at identifying letters of the alphabet compared to younger adults. However, after many trials of practice over five days, older adults were able to speed up their performance just as much as the younger adults did. That is, there were significant increases in speed with practice for both age groups, and the learning curves for both age groups were basically the same. Another study of pattern recognition by Russo and Parkin (1993) asked participants to identify common objects when only fragments of these objects were presented. Again, an age deficit was found in this type of learning, although learning still occurred in the older age group.

Finally, perceptual learning has been investigated using the visual search task. In this task, the subject must search a visual display for a 'target' item (e.g., a specific letter or number) that is embedded amongst other items ('distractors'). The visual search task can either be given under consistent mapping conditions (CM) where the target items appear only as targets and never as distractors, or under variable mapping conditions (VM) where the target items appear sometimes as targets and sometimes as distractors. Under CM conditions, subjects are always dealing with a class of stimuli in the same way, and thus their reaction times should become significantly faster with practice, and performance should become automatic. However under VM conditions, subjects must always be attentive to stimulus changes, and as such their reaction times should not decrease significantly, and their performance should remain effortful. Fisk and Rogers (1991) studied the performance of young and older adults in visual search tasks. They found that after extensive practice in visual search, young adults displayed the expected results – that is, under CM conditions their performance became faster and automatic, while under VM conditions it did not. However, older adults did not display the expected results after extensive practice – under CM conditions their performance remained slow and effortful, and resembled performance under VM conditions. These results have been replicated in other visual search studies (e.g., Davis, Fujawa, & Shikano, 2002; Fisk, Rogers, & Giambra, 1990; Rogers, 1992; Rogers, Fisk & Hertzog, 1994). Even when older adults are given extra practice sessions compared to younger adults, their reaction times do not become significantly faster under CM conditions (Gilbert & Rogers, 1996).

On the other hand, several studies have found that the performance of older adults becomes as fast and automatic as younger adults under CM conditions, when the task involves conjunction search rather than simple-feature search (e.g., Ho & Scialfa, 2002; Scialfa, Jenkins, Hamaluk, & Skaloud, 2000). In conjunction search, subjects are required to search for targets defined by the conjunction of two features (e.g., form and colour), while in simple-feature search, subjects are required to search for targets defined by single features only (e.g., form). The finding that older adults can improve to the same extent as younger adults in CM conjunction search has been attributed to the characteristics of the targets in conjunction search. For example, a target with conjoined features differs from the distractors in two ways, which makes it more discriminable to the subject, whereas a single-feature target differs from the distractors in just one way. However, evidence of automaticity in older adults in CM conjunction search has not been found consistently across studies. For example, several studies have found that older adults are significantly slower than younger adults in conjunction search compared to single-feature search (e.g., Humphrey & Kramer, 1997; Plude & Doussard-Roosevelt, 1989). There could be several reasons for these contradicting results. For example, studies often differ in the number of practice trials given to subjects, the features used to define the stimuli, the display sizes used, and the complexity of the tasks given.

Studies have also been conducted in memory search, which requires subjects to study a number of items presented to them (called the memory set), and to hold these items in memory. The memory set is then removed from view, and subjects must determine whether a single item on display was part of the original memory set or not. Therefore, memory search differs from visual search in that it involves committing several items to memory and being presented with only one item at a time on the computer screen. Several studies have found that older adults improve as much as younger adults in consistent mapping (CM) memory search, such that both age groups achieve automaticity in the tasks (e.g., Fisk, Cooper, Hertzog, Anderson-Garlach, & Lee, 1995; Fisk, Rogers, Cooper & Gilbert, 1997). However, the performance of both age groups remains slow and effortful in the variable mapping (VM) condition. The finding that older adults achieve automatic performance in CM memory search has been attributed to associative learning, which seems to remain intact with age. Strayer and Kramer (1994), however, found that age differences do exist in CM memory search. They attribute their different results to the greater difficulty level of their memory search task compared to other studies (i.e., their largest memory load was 6) and to presenting their memory set after every 24 trials rather than after every trial.

Thus, when learning perceptual skills, older adults do seem to improve in their accuracy and speed with practice. While in most perceptual tasks, the improvements of older adults are not as large as those of younger adults, in some tasks (such as CM visual conjunction search and CM memory search), older adults seem as able as younger adults to achieve automaticity. The age-related declines seen in most perceptual tasks, however, may be caused by changes in the visual system that occurs with age. In terms of vision, aging is associated with impaired visual acuity, impaired contrast sensitivity, far-sightedness, a diminished ability to discriminate colours, decreased visual tracking and a decreased useful field of view (see Chapter 1). Furthermore, aging is associated with a deterioration of the visuo-spatial processing areas of the brain, which may affect the learning ability of older adults in perceptual tasks (Lapidot, 1987; see Chapter 3 for more information).

Cognitive Skills

According to VanLehn (1996), "cognitive skills acquisition is acquiring the ability to solve problems in intellectual tasks, where success is determined more by the subjects' knowledge than their physical prowess" (p. 513). Examples of cognitive skills include performing mental arithmetic, puzzle solving, elementary geometry, and computer programming (Anderson 1982, 1993; Rosenbloom, Laird, & Newell, 1993; VanLehn, 1996).

Little research has been conducted on the effect of age on cognitive skill acquisition. In one study by Charness and Campbell (1988), the acquisition of mental calculation was investigated in young, middle-aged and older adults. Subjects were required to learn a mental squaring algorithm of the form $a^2 = (a + c)(a - c) + c^2$ in order to perform the task of squaring numbers. The numbers given ranged between 1 and 99. The results were that older adults learned and forgot the skill at about the same rate as younger adults, although their calculation speed was much slower than that of younger adults. Nevertheless, it took the older adults about 3 minutes of practice (per year of age difference) to equal the initial performance of younger adults. Therefore, the three age groups differed in how quickly they performed the cognitive skill, but not in how they acquired the skill.

In a later study by Jenkins and Hoyer (2000), young and older adults performed an enumeration task in which they had to report the number of items in visual displays of 6 to 11 targets. The researchers believed that in the early stages of the task, subjects would thoroughly search the visual displays and count the number of items (using a counting algorithm) in order to report the correct numerosity. However, with practice, the researchers predicted that subjects would store increasing numbers of instances (displays and solutions) in their memory. Thus, with practice, there would be an increased probability that retrieving a solution from memory would take less time than generating a solution using a counting algorithm. This would cause the reaction times of subjects to decrease until reaction times finally reached an asymptote. The asymptote indicates that performance has become automatic and that performance is based on instance retrieval rather than algorithmic computation. In this experiment, the researchers found that older adults required more practice than younger adults to reach the asymptote. The learning rates for older adults were also slower than for younger adults, suggesting that younger adults achieved automaticity faster than older adults. Nevertheless, these results show that older adults are capable of achieving automatic performance in a cognitive skill.

A study by Peretti, Danion, Gierski, and Grange (2002) investigated cognitive skill learning in young and older adults using a Tower of Toronto (TT) puzzle, a variant of the Tower of Hanoi. In this task, participants are presented with a rectangular block with three pegs and four disks of different colours. All disks are initially on the leftmost 'start' peg, with the darkest disk at the bottom and the lightest disk on the top. Individuals are then asked to move the disks from the start peg and to reassemble the disks in their original order on the rightmost 'goal' peg. However, participants are only allowed to move one disk at a time, and they can never place a darker disk on top of a lighter one. Participants were required to solve this puzzle in three blocks of eight trials, with 30-minute breaks in between blocks. The results were that older adults needed more trials to find the optimal solution, and they made significantly more rule violations, compared to the younger adults. Despite this, the performance of older adults improved with practice in the same way as it did for younger adults. That is, the learning rates were identical for young and older adults.

In another study by Touron, Hoyer and Cerella (2001), young and older adults were asked to either produce or verify solutions to alphabet arithmetic problems. In the verification task, subjects were given equations of the form 1 + A = 2 or 3 + D = 7 and asked to verify whether the equations were true or false. In the production task, subjects were given equations of the form 1 + A = ? and 3 + B = ? and asked to produce answers to these equations. When power functions were fitted to the data and the parameters of these functions analysed, the results showed significant age differences favouring the younger adults. Specifically, the results indicated that the amount of improvement for younger adults (in terms of reaction times) was greater than for older adults, and the learning rates and final reaction times of younger adults were faster than those of older adults.

In a similar study by Brigman and Cherry (2002), young and older adults were required to perform an alphabet arithmetic task. In this task, participants were required to verify the accuracy of letter-number-letter strings (e.g., J[2]M, K[3]P). The number in the brackets indicated the number of letters to be skipped in the alphabet in order to go from the first letter of the string to the last letter. Thus, J[K,L]M represents a 'true' sequence, whereas J[K,L]N represents a 'false' sequence. Participants were required to give their responses using keys on a keyboard. The results of the experiment indicated that older adults were slower than younger adults in acquiring the alphabet arithmetic skill. However, both age groups showed a substantial decrease in reaction time with practice, suggesting that both age groups were actively learning the task.

In conclusion, most of the research on cognitive skill acquisition indicates that older adults are slower and make more errors than younger adults when performing new cognitive skills. Age-related changes in the brain and nervous system could account for this age-related slowing and decline in performance. For example, age-related atrophy of the brain can account for changes in the information-processing ability of older adults, as well as changes in other cognitive processes such as working memory (see Chapter 1). Nevertheless, older adults seem capable of acquiring new cognitive skills, although they often acquire these skills at a slower rate compared to younger adults.

Implicit Learning

Implicit learning refers to the “learning [of] complex information without complete verbalizable knowledge of what is learned” (Seger, 1994, p. 163). It is an unconscious process whereby the individual acquires knowledge without deliberately trying to do so. For example, the learning of a task’s processes and procedures (‘procedural learning’) will often occur unconsciously, such that individuals will not be able to verbalise what they have learned. Therefore, many researchers consider procedural learning to be a form of implicit learning (eg., Ashby et al., 1998; Cohen & Squire, 1980; Shanks & St John, 1994; Squire, 1986). Conversely, explicit learning involves the conscious use of strategies to gain knowledge about a task (O’Brien-Malone & Maybery, 1998).

Moscovitch, Winocur, and McLachlan (1986) studied implicit learning in young and older adults by asking them to read sentences in both normal script and geometrically transformed (180° rotated) script. Participants read 28 sentences at baseline, 28 sentences 1-2 hours later, and 56 sentences two weeks later, and their reading times for transformed sentences were recorded. In the two later sessions, individuals were presented with sentences from the baseline phase, as well as novel sentences that had not been presented before. The reading times for these novel sentences became faster in later sessions, and this occurred at an approximately equal rate for each age group. This suggests that the older adults were as capable as younger adults to learn a general pattern-recognition skill, without being told to do so and without being consciously aware of it. Furthermore, with each session both age groups became faster at reading the familiar sentences, and again improved at an approximately equal rate. When participants were asked whether or not the sentences were old (i.e., had been read before) or new (i.e., not read before), older adults were less able to distinguish between the sentences compared to the younger adults, especially after 2 weeks. This supports the notion that compared to younger adults; older adults are less able to consciously recollect information, but just as able to learn information implicitly.

In a different experiment by Hashtroudi et al. (1991; Experiment 1), subjects were asked to read inverted words rather than sentences. Again, a combination of new words and repeated words were presented to participants over a series of nine trials. The number of new words read correctly was recorded for each trial. The results indicated that both young and older adults increased their ability to read new inverted words with each trial. However, this improvement was slower for older adults than for younger adults. The researchers thought that the exposure duration of 450ms for each word was too fast for the older adults. Thus, they increased the exposure duration to 900ms and found that under this condition, the learning rate of older adults was equal to that of younger adults. That is, the proportion of new words read correctly increased at an equal rate over the nine trials for both age groups. The researchers concluded that both age groups could learn a general word-reading skill without being told to do so and without being consciously aware of it.

Myers and Conner (1992) also investigated implicit learning and aging by asking young and older adults to perform a complex cognitive task. The task involved controlling a computer system to achieve specified outputs under different conditions. The investigators found that after extensive practice, both age groups performed the task at equal levels of accuracy, although older adults did take more time to complete the trials. Furthermore, both age groups showed no relationship between what they knew (in terms of verbal knowledge) and how well they performed. This suggests that both age groups were able to learn the task implicitly.

Howard and Howard (1989) employed a serial-reaction-time task to investigate implicit learning in young and older adults. The task required participants to look at a computer screen on which a pattern of either 10 asterisks or 16 asterisks was presented over many trials. Each pattern required particular keyboard responses from the participants. After four blocks of trials, both age groups decreased their response times equally for both patterns, suggesting that they had 'learned' the recurring patterns. A fifth block of trials was then given to participants, in which the asterisks appeared in a different random order for each trial. In this block of trials, the previous learning of patterns and responses would not have been helpful, and consequently the reaction times increased for each age group. Participants were then given a 30-minute break, followed by three more blocks of trials. In these trials, individuals were presented with the original/initial patterns of the experiment, and further reductions in their reaction times occurred. The researchers concluded from these results that young and older adults were equally capable of implicit learning when conscious recall of the patterns was not required.

To determine whether explicit learning occurred during this experiment, Howard and Howard (1989) presented participants with a final block of trials in which they were required to consciously remember the repeated patterns. Each trial involved the presentation of a sequence of asterisks, with individuals asked to predict the location of the next asterisk. The researchers found that the young adults were significantly better than the older adults at predicting the location of the asterisks, for both the short pattern sequence and the long pattern sequence. This suggests that older adults are impaired at learning when asked to consciously recollect what they have learned (i.e., when learning is explicit). However, older adults are as capable at learning as younger adults when conscious recollection of the information is not required (i.e., when learning is implicit).

Unfortunately, the findings from Howard and Howard (1989) were not replicated in their later study. In Howard and Howard (2001), young and older adults were required to perform an alternating serial response time task, where predictable patterns were alternated with random patterns in a visual display. Half of the participants were told about the pattern sequence and asked to uncover it (intentional instructions) while the other half were not (incidental instructions). The investigators found that the performance of older adults was impaired when they tried to uncover the pattern, whereas the performance of younger adults was improved under this condition. However, the performance of older adults was also impaired when they were unaware of the pattern sequence, suggesting that older adults did not engage in any implicit learning for this task. This age-related deficit in implicit learning has also been found in middle-aged adults (Feeney, Howard, & Howard, 2002).

Similar results were obtained in an experiment by Harrington and Haaland (1992). In this study, young and older adults were given a serial-reaction-time task involving hand postures. Participants were required to perform hand postures based on pictorial information presented on a computer monitor. In one experimental condition, the pictorial information was repeated cyclically, so that participants performed the same motor sequence of hand postures over many trials, without being told of this sequence. In the other experimental condition, however, the pictorial information was not repeated cyclically, so that participants performed novel sequences of hand postures over many trials. The performance of young adults in this experiment (in terms of movement time) improved in both conditions, suggesting that procedural learning occurred for this age group. However, the performance of older adults did not improve in either condition, suggesting that older adults did not engage in either implicit learning or explicit learning for this task.

D'Eredita and Hoyer (1999) used figural sequences to study the effect of age on implicit learning. Young, middle-aged and older adults were required to learn sequences of visual-spatial transformations of a complex figure. The figure changed in size, orientation, or had parts of it darkened or removed, as participants looked from left to right. In the acquisition phase of the experiment, half the participants in each age group learned figural sequences in which the item-to-item changes were based on an artificial grammar, while the other half of the participants learned figural sequences in which the item-to-item changes were nongrammatical. In the testing phase of the experiment, individuals in each age group were given either explicit or implicit instructions. Individuals who were given the explicit instructions were told to recall the figural sequences from the acquisition phase in order to complete the figural sequences in the testing phase. However, individuals who were given the implicit instructions were simply told to complete the figural sequences in the testing phase as best they could. No information was given to any of the participants in either condition, regarding the regularities of the sequences or the presence of an artificial grammar. The results were that under implicit instructions, all age groups performed at chance level during the testing phase, whether the figural sequences were grammatical or not. This suggests that implicit learning did not occur for any age group in this task. However, under explicit instructions, participants were able to use previously learned information about figural sequences to help them complete the grammatical test sequences. An age-related deficit was found in the ability of individuals to do this, suggesting that explicit learning is impaired in older adults compared to younger adults.

The results from these experiments suggest that the occurrence of learning and the type of learning exhibited by older adults (i.e., implicit learning vs explicit learning) is largely dependent on the type of task given in the experiment (Kausler, 1994). However, the results from most of the studies suggest that implicit learning remains intact with age, whereas explicit learning becomes impaired with age.

Transfer of Skill

According to Singley and Anderson (1989), "the study of transfer is the study of how knowledge acquired in one situation applies (or fails to apply) in other situations" (p. 1). Cognitive psychologists are interested in the mechanisms that enable or prevent skills to be transferred to other situations. Skills that can be applied to contexts other than the one in which they were acquired are often referred to as 'general skills' whereas skills that are specific to the context in which they were acquired are often referred to as 'specific skills' (Singley & Anderson, 1989).

One of the first theorists to study the transfer of skill was Thorndike (1913). He proposed the theory of identical elements, whereby transfer between tasks occurs only if the two tasks share common stimulus-response elements. He believed that "one mental function or activity improves others insofar as and because they are in part identical with it, because it contains elements common to them. Addition improves multiplication because multiplication is largely addition; knowledge of Latin gives increased ability to learn French because many of the facts learned in the one case are needed in the other" (Thorndike, 1913, p. 243). That is, Thorndike thought that transfer between diverse skills was possible as long as the skills contained identical elements.

While Thorndike's own experiments offered some support to his theory (e.g., Thorndike, 1922; Thorndike & Woodworth, 1901), his subjects were often able to transfer some skill to a similar task, even when identical elements were not present. Furthermore, theorists argued that Thorndike's theory of identical elements was incompatible with the notion of transfer, which stresses adaptation and flexibility. That is, if transfer can only occur in situations where the same responses to the same stimuli are required, then the individual is simply doing the same as before rather than something new and adaptive (Singley & Anderson, 1989). A second argument focused on the meaning of the terms 'identical elements'. It was the claim of many theorists that "no two situations are truly identical; they are merely perceived as such psychologically" (Singley & Anderson, 1989, p. 6). This concern made Thorndike's theory troublesome when applied to the real world. In response to these criticisms, psychologists came up with new theories throughout the years to explain the phenomenon of transfer. Just as with the acquisition of skill, the main theories of the transfer of skill at present are Anderson's ACT* Theory (1982, 1983, 1987) and Logan's Instance Theory (1988, 1990).

Transfer Predictions of the ACT Theory*

Anderson's ACT* Theory (1982) is a general theory of skill acquisition because it suggests that skills are general in nature and that they can be applied to contexts other than the one in which they were acquired. However, the degree to which skills will transfer from one task to another will depend on the number of shared task components. More specifically, it will depend on the extent to which the same productions are involved in performing the two tasks. Therefore, the amount of transfer should be high when going from one set of problems to another set of similar problems that can be solved using the same productions.

This theory has been supported by numerous studies. For example, Neves and Anderson (1981) studied the ability of participants to do geometric proofs compared with their ability to justify the statements of a worked-out proof. Even though both of these tasks required the same kind of knowledge, the productions needed to carry out each task were very different. Therefore, it was predicted that positive transfer would not occur from one task to another. Indeed, Neves and Anderson (1981) found that after ten days of practice at justifying worked-out proofs, there was no significant positive transfer to the task of generating proofs.

Singley and Anderson (1985) studied transfer between computer text editors: ED, EDT and EMACS. The goal structure was identical for ED and EDT (same way of editing), but the surface structure was different (different command names for same functions). The goal structure was different for EMACS (different way of editing), but the surface structure was similar to ED and EDT (same command names). The prediction was near perfect transfer between text editors when the goal structure was identical (i.e., between ED and EDT), and little transfer when the goal structure was different (i.e., between ED/EDT and EMACS). The results supported this prediction. Singley and Anderson (1985) then studied transfer between EMACS and perverse EMACS (which have the same goal structure as EMACS but a different surface structure), and as predicted, there was little effect of changing to perverse EMACS.

In a study by Kieras and Bovair (1986), 60 participants learned a series of related procedures for operating a control-panel device, by reading the step-by-step instructions. Individuals were placed in three groups, and were taught the procedures in different training orders. The results showed strong positive transfer when the individual production rules from one procedure could be transferred or re-used in the next procedure.

McKendree and Anderson (1987) studied transfer with LISP computer programming skills. In one task, participants were required to *evaluate* the results of LISP functions applied to arguments. In the other task, participants were required to *generate* LISP expressions. Again, the productions needed to solve the evaluation problems were different to those needed to solve the generation problems, even though the productions for both tasks were based on the same declarative knowledge. The results from the experiment showed that little transfer occurred between the evaluation task and the generation task. This reinforces the idea that productions need to be the same in two similar tasks, in order for positive transfer to occur.

Novick (1988) studied transfer in the solving of complex arithmetic word problems. Expert participants were presented with problems in a training phase, followed by a different set of problems in a transfer phase. Problems in the transfer phase could have the same structural features but different surface features to the original problems, or they could have the same surface features but different structural features to the original problems. The results were that positive transfer occurred when problems in the transfer phase had the same structural features but different surface features to the original problems. That is, positive transfer occurred when problems in training and transfer had the same goal structure, which supports Anderson's ACT* theory.

In a study by Frensch (1991; Experiment 2), the process of composition (from Anderson's ACT* theory) was investigated thoroughly in transfer. In this experiment, participants were trained to perform a six-step mental arithmetic task. It was assumed that subjects would learn this task by chunking or composing multiple productions together, to create a smaller number of more efficient productions. Subjects were then presented with one of two transfer tasks that were identical in structure to the original arithmetic task, but were different in the amount of composed productions that they shared with the original task. For example, to perform the first transfer task, subjects were only able to use one of the composed steps from the original task. To perform the second transfer task, however, subjects were able to use two of the composed steps from the original task. Frensch predicted that the performance of subjects would be faster for the second transfer task than for the first transfer task, because the second transfer task shared more composed steps with the original task. The results supported this prediction, suggesting that the process of composition does play a vital role in skill acquisition and transfer.

Therefore, there is some empirical evidence for Anderson's (1982) theory that skills transfer from one task to another depending on the number of shared task components or productions, and that the process of composition is an important factor in transfer.

Transfer Predictions of the Instance Theory

Logan's Instance Theory (1988, 1990) is a specific theory of skill acquisition because it suggests that skills are specific to the context in which they are acquired, and cannot be easily transferred to a new context. Transfer to a new context is possible, but only if the new task involves specific events that have been encountered in the old task. That is, transfer will only occur if the new task involves the retrieval of the same instances as was used in the old task. If the new task has different stimulus conditions to the old task, then no instances can be retrieved, and performance will depend on the execution of an algorithm instead. In this case, performance will resemble pre-practice levels. There have been numerous studies supporting this viewpoint.

A series of experiments conducted by Masson (1986) on typographically transformed words endorse the transfer predictions of instance theory. These experiments found that transfer of word identification skill was highly specific, in that transfer occurred only when training and test instances shared common letters and were printed in the same case (i.e., uppercase or lowercase). Therefore, the idea of item-specific learning was supported in this case.

Another study by Logan and Klapp (1991) used an alphabet arithmetic task to test the transfer predictions of the instance theory. With this task, participants were given equations of the form A + 2 = C or B + 3 = E and asked to verify whether the equations were true or false. Initially, it was assumed that participants counted forward through the alphabet (with the distance being determined by the digit addend, e.g., 2) from the initial letter (e.g., A), and compared the resultant letter with the letter that is presented (e.g., C). With practice, this counting algorithm could be replaced by memory for alphabet-arithmetic facts. Participants in this experiment were first trained to perform this task with problems that used letters from one half of the alphabet (A-J or K-Z) and then asked to perform the task with problems that used letters from the other half of the alphabet (K-Z or A-J). This changing of stimulus conditions in the transfer phase means that transfer should not have occurred at all (according to the Instance Theory). The results partially supported this prediction - reaction times for the transfer phase were significantly slower than reaction times for the last session of the training phase. However, reaction times during the transfer phase did not return to the very slow pre-training levels. That is, some amount of positive transfer did occur between tasks, which is not entirely consistent with Logan's predictions.

Green (1997) used a visual numerosity task to investigate the instance theory's transfer predictions. During a training phase, participants were presented with repeated patterns of 8 to 10 items on a computer screen, and asked to count the items on the screen. During the transfer phase, participants were presented with patterns that differed from the original patterns, either in terms of the overall pattern configuration, or in terms of the item identities (i.e., using 'bottles' for the 8-item pattern; 'bunnies' for the 9-item pattern, and so on). Since the patterns were different in the transfer conditions, participants could not rely on the original learned patterns to determine the numerosity of the new patterns. Thus, instance theory predicted that the performance of subjects would be impaired in the transfer conditions. This prediction was supported. However, the fact that performance did not return to pretraining levels suggests that subjects were also engaging in general learning (consistent with Anderson's ACT* theory).

Logan (1998) tested the instance theory transfer predictions using a category search task. In this task, subjects were required to search through one- or two-word displays for members of a target category (e.g., metals). During the training phase, target items appeared consistently in the same locations, while during the transfer phase, the locations of targets were changed. Logan predicted that performance would be disrupted in the transfer phase, because the visual displays had been changed. However, changing the locations of targets did not have a detrimental effect on the performance of participants. Logan interpreted this as meaning one of two things: either the participants did not encode the target locations as instances, or target locations were encoded but not retrieved. One possible cause of retrieval failure was that too many words were associated with too few locations (only two locations). When words were presented in 16 different locations instead, performance was impaired at transfer. Therefore it seems that individuals do encode the locations of targets as instances, such that performance is impaired when the locations are changed at transfer. Other studies on category search (e.g., Schneider & Fisk, 1984) have also found initial disruption when participants are required to search for exemplars of a certain category in training (e.g., the words 'cat' and 'elephant' for the category of animals) and then required to search for new members of a category at transfer (e.g., the word 'bear'). However, the presence of high positive transfer supports the notion that learning in category search is both specific and general.

Speelman and Kirsner (2001) investigated transfer using a fictional water analysis task. This task involved performing a sequence of simple calculations so as to convert data into measures of water purity. The equations used for the calculations remained fixed and identical in each trial. During the training phase of this experiment, participants were required to perform three calculations to convert novel data into measures of water purity. In the transfer phase of the experiment, participants were required to perform the same three calculations plus two new calculations, to convert novel data into measures of water purity. Thus, the task was identical in the training and transfer phase, except for the number of calculations to be performed on each trial. According to Logan's theory, the task in the transfer phase can be seen as a 'new' task, since it has new added components. Thus, old skills should not be transferred to this task, because the context of the task has changed. The results indicated that performance was disrupted and became slower in the initial stages of the transfer phase. However, performance did not return to the very slow pre-training levels, suggesting that some positive transfer did occur. Again, this does not fully support Logan's predictions.

In conclusion, it seems that the transfer of skills to other contexts is possible and made easier when specific events in the new task are the same as in the old task. However, empirical research suggests that some amount of positive transfer does occur, even when the new task has specific events that were not encountered in the old task. This suggests that learning can be both specific and general. Therefore, Logan's Instance Theory (1988) is not entirely supported.

Testing Transfer Predictions of Both Theories

General theories of skill acquisition (such as Anderson's ACT* Theory) predict positive transfer between tasks that share the same processes or productions. Therefore, item-specific information is not important. If two tasks are similar in nature and involve the same processes for performance, then skills should transfer from one task to the other, regardless of the nature of the individual items in the tasks. In contrast, specific theories of skill acquisition (such as Logan's Instance Theory) predict no transfer between similar tasks because although the tasks share the same processes, they do not share the same individual items. Since performance depends on the retrieval of past solutions to specific items, it would not be possible to retrieve solutions if the task involved new items that had not been solved before. Therefore, performance in the new task would be the same as initial performance in the first task.

Several studies have tested the transfer predictions of both theories of skill acquisition. Kramer, Strayer and Buckley (1990) asked participants to perform a rule-based memory search task. In the training phase of this task, individuals had to memorise one, two or three rules (the memory set). They were then presented with 30 probe stimuli (exemplars), and were asked to determine whether each exemplar matched a memory set rule or not. In the transfer phase of the task, the same rules were used but the individual exemplars were changed. Anderson's ACT* theory predicted high positive transfer for this situation, because the goal structure of the task remained the same at transfer, even though the individual stimuli were changed. On the other hand, Logan's instance theory predicted no transfer, since the stimuli were changed at transfer, and instances involving the original stimuli (stored in memory) were no longer useful for subjects during the transfer phase. The results of this experiment indicated that high positive transfer occurred to situations in which the individual exemplars were changed. Thus, the results strongly suggest that learning in this task was general rather than specific, as described by the ACT* theory.

Knowlton and Squire (1996) studied artificial grammar learning in amnesic patients and controls. During the training phase of this task, participants were presented with a series of letter strings that were constructed based on a rule system. After seeing each letter string one at a time, individuals were given three chances to reproduce the letter-strings from their short-term memories. Each letter-string was presented repeatedly across trials. In the transfer phase of the task, individuals were presented with new letter-strings that still followed the original rule system. The results were that performance was impaired when participants were presented with these different letter-strings in the transfer phase. This implies that participants learned exemplar-specific information during training, which supports the instance theory. However, performance for both groups was still above chance-level when different letter-strings were used in transfer, suggesting that some positive transfer of a general skill did occur. Therefore, these results also support Anderson's ACT* theory. The researchers conclude that both groups of participants gained abstract rule-based knowledge (i.e., general learning) as well as exemplar-specific knowledge (i.e., specific learning). Moreover, amnesic patients were severely impaired compared to controls during a recognition task, in which they were asked to determine whether or not letter-strings were presented during training or not. Amnesic patients found it difficult to explicitly recognise the letter-strings that were presented during training, even though their performance at transfer indicated that they did learn to recognise the letter-strings during training. Therefore, the results suggest that amnesic patients were learning the item-general and item-specific information during training without consciously or deliberately intending to. This implies that general and specific skills for this task can be learned implicitly.

Speelman and Kirsner (1997) conducted a different experiment that required individuals to solve syllogisms. The syllogisms were of the categorical type, and used universal affirmative premises (e.g. "All of the artists are beekeepers; All of the beekeepers are chemists; Therefore all of the artists are chemists"). All syllogisms used in the experiment had the same format, and no syllogism was repeated. However, all syllogisms could be solved using the same strategy. The fact that no items were repeated during the experiment means that the storage of instances would not help participants improve, since the same syllogism was never presented twice. Therefore, according to instance theory, the performance of participants would not improve with practice. However, performance did improve with practice, thereby contradicting the instance theory's predictions. Anderson's ACT* Theory seemed better able to explain this result.

Ward and Churchill (1998) used an invariant mental arithmetic task to investigate the transfer predictions of the two skill acquisition theories. During the training phase of this task, participants were asked to perform simple mental arithmetic calculations on thirty strings of 4-digit numbers. For half of the participants, the number strings followed a hidden rule: all the stimuli contained the number '3' (the invariant feature). However, the stimuli for the other half of the participants did not follow a hidden rule, and did not contain the number '3'. The participants were required to compare the sum of the first pair of digits with the sum of the last pair of digits, to determine which sum was the greatest. During the test phase, participants were presented with ten pairs of new digit strings that they had not encountered before. For each test pair, one digit string contained a 3 (a positive instance), and one did not (a negative instance). Participants were instructed to click on the digit string (in each pair) that they thought they had seen before in the training phase. Anderson's ACT* theory predicted that participants exposed to the rule-based stimuli during training would learn the abstract rule and use it in the test phase. That is, participants in the '3s' condition would pick more positive instances and would perform significantly better than participants in the 'no 3s' condition. On the other hand, Logan's instance theory predicted that the performance of participants would be approximately equal in both conditions. This is because participants in both conditions are committing specific stimuli (instances) to memory, whether the stimuli contain 3's or not. The results were that the same degree of learning occurred in both conditions. The researchers concluded that participants engaged in specific instance-based learning rather than general rule-based learning for this task.

Greig and Speelman (1999) also studied the transfer predictions of skill acquisition theories using a mathematical task. Participants were required to solve an algebraic equation of the form $(x^2 + 2y)$ by substituting values for x and y (e.g., $x = 1$ and $y = 3$). In the training session, values for x and y were taken from a small, fixed set of values. Each x and y pair was presented several times during the training phase. In the transfer phase, participants were required to solve the same equation, but the values for x and y were taken from a different set of values to those used during training. As before, x and y pairs were presented repeatedly during the transfer phase. Since this experiment used the same task in both phases, participants were able to use the same strategy to perform in both phases. Therefore, the ACT* theory predicted complete positive transfer from one phase to the next. That is, performance in the transfer phase would be equal to that achieved in the training phase. However, since different items were used in each phase, instance theory predicted no transfer between tasks. This is because the solutions learned in the training phase would not be applicable to the problems presented in the transfer phase. The result was that partial transfer occurred from one phase to another, such that participants engaged in both general and specific learning during training. This result is problematic for the instance theory of skill acquisition, but not for the ACT* theory of skill acquisition, which can account for both item-general and item-specific skill acquisition. According to ACT* theory, subjects initially developed item-general productions to solve the equation for any set of x and y values. With practice, subjects were then able to develop item-specific productions that were specific for certain x and y pairs. In the transfer phase, the item-specific productions developed in training were no longer appropriate. This can explain why performance was slower in the initial stages of the transfer phase compared to the end stages of the training phase. However, subjects were still able to use the item-general productions developed during training, which can explain why their performance in the transfer phase did not return to pre-training levels.

In summary, Anderson's ACT* Theory (1982) is better able to explain the research data on skill transfer than Logan's Instance Theory (1988). This is because the ACT* theory can account for both item-general and item-specific skill acquisition, whereas Logan's Instance Theory accounts for only item-specific learning.

Age and Transfer Predictions

The study of aging and transfer is still a relatively new area. One study mentioned before, by Moscovitch et al. (1986), asked young and older adults to read sentences in both normal script and geometrically transformed (180° rotated) script. After an initial training session, participants underwent two testing sessions (1-2 hours later, and 2 weeks later) where they were presented with sentences that had been presented earlier, as well as novel sentences that had not been presented earlier. The results were that reading times for both novel sentences and familiar sentences became faster in later sessions, at an approximately equal rate for each age group. This suggests that both age groups learned a general pattern-recognition skill that could be transferred to novel stimuli, rather than a specific pattern-recognition skill.

In another study mentioned earlier, by Howard and Howard (1989), a serial-reaction-time task was used to investigate the learning ability of young and older adults. The task required participants to respond to a pattern of either 10 asterisks or 16 asterisks on a computer over many trials. After many trials, both age groups decreased their response times equally for both patterns, suggesting that they had 'learned' the recurring patterns. This learning may have been the result of both general learning whereby individuals learn the general features of the task, and specific learning whereby individuals learn the specific features of each stimulus. Howard and Howard (1992; Experiment 2) investigated what type of learning participants used by creating two experimental conditions: one condition in which a new random pattern was used for each block of trials, and one condition in which the same pattern was used for each block of trials. The results were that participants did not improve their reaction times with practice in the random-pattern condition, but they did improve their reaction times in the repeated-pattern condition. Moreover, the reduction in reaction times with repeated patterns was approximately equal for both age groups. According to Howard and Howard, "this pattern suggests that general practice with the task (the random group) was having little effect on response times and that most of the improvement seen in the patterned groups was due to specific learning of the pattern" (1992, pp. 237-238). This seems to directly contradict the results of Moscovitch et al. (1986) where participants were thought to have learned a general skill rather than a specific skill.

The experiment mentioned earlier by Charness and Campbell (1988) also studied aging and transfer by looking at the acquisition of mental calculation in young, middle-aged and older adults. Participants were required to learn a mental squaring algorithm of the form $a^2 = (a + c)(a - c) + c^2$ in order to perform the task of squaring numbers. After the training phase participants underwent a transfer phase in which they performed the same task, but were given a different set of numbers to square. The results showed partial transfer for each age group. This supports Anderson's ACT* theory in which participants acquired both item-general and item-specific productions in the training phase, but were only able to use the item-general productions in the transfer phase. Furthermore, there were no age differences in terms of the way in which they acquired the mental squaring skill.

A different set of results was reported by Fisk and Rogers (1991), who studied the performance of young and older adults in visual search tasks. Under consistent mapping (CM) conditions, performance in visual search is expected to become automatic with practice, because participants are always dealing with targets and distractors in the same way. However under variable mapping (VM) conditions, participants must always be attentive to stimulus changes, and as such their performance is not expected to become automatic with practice. Thus, both conditions allow for the development of general search skills to perform the task, but only in the CM condition can participants develop specific skills (item-specific productions according to ACT*; specific instances according to instance theory) that allow for automaticity. Fisk and Rogers (1991) found that after extensive practice in visual search, the performance of young adults became automatic under CM conditions (as expected), while under VM conditions it did not. However, the performance of older adults did not become automatic under either condition. This suggests that older adults were learning general skills in both conditions, and did not develop specific skills required for automaticity in the CM conditions. Thus, both young and older adults seem to learn general skills in visual search tasks, but only the young adults learn specific skills necessary for automaticity.

A related study by Fisk, Hertzog, Lee, Rogers and Anderson-Garlach (1994) examined long-term retention of skilled visual search in young and older adults. All participants received extensive CM visual search training (3000 trials) and were tested again 16 months later. Retention of skilled visual search was assessed using old stimuli (used in initial training) and new stimuli. Old stimuli were used to assess the retention of item-specific learning, while new stimuli were used to assess the retention of item-general learning. Since Fisk and Rogers (1991) found that older adults did not learn specific skills in visual search, Fisk et al. (1994) predicted low retention of stimulus-specific learning in these subjects. This prediction was supported. Furthermore, Fisk et al. (1994) found no age-related retention differences in general- skill learning, suggesting that both young and older adults learn general skills to the same extent in visual search.

Myers and Conner (1992) studied the influence of aging on transfer using an implicit learning task. During the training phase, young and older adults were taught to control a computer system to achieve specified outputs under different conditions. During the transfer phase, participants were required to perform a task that either had a similar surface appearance to the training task, or a different surface appearance to the training task. That is, subjects in the transfer phase were presented with the same task in a similar context, or the same task in a new context. ACT* theory predicted positive transfer between the tasks, since the underlying structures of the tasks remained the same. However, instance theory predicted that no transfer would occur between the tasks, since the new surface appearance would contain new stimuli. The results were that younger adults showed positive transfer to the task with the new surface appearance, whereas older adults did not. In fact, the older adults only showed positive transfer when the transfer task used a semantic domain that was similar to the original task (i.e., when the transfer task's surface appearance was similar to the original task). This implies that older adults are dependent on the surface features of a task during skill acquisition. Therefore, this study is at odds with visual search studies, since older adults engaged in specific learning in this task.

Jamieson and Rogers (2000) investigated aging and transfer by training young and older adults to use a simulated automatic teller machine (ATM). The ATM used in the training phase (ATM1) had all the standard features and options of a normal bank ATM. However, the ATM used in the transfer phase (ATM2) had the same features as ATM1, except that the surface layout of the features was different. Also, the ATM2 had additional options that were not offered on the ATM1. Since the context of the task changed in the transfer phase, instance theory predicted no positive transfer to occur between the two ATM's. However, since the goal structure and procedural information remained the same in the transfer phase, ACT* theory predicted high positive transfer between the two ATM's. The results were that both age groups showed positive transfer to the new ATM, with the younger adults showing higher positive transfer than the older adults. This suggests that older adults are more susceptible to changes in task surface features than younger adults. That is, while both age groups engaged in item-general learning, older adults seemed to rely more on item-specific learning than younger adults, because changes in task context caused greater detriments to their performance than to the younger age group.

The study mentioned earlier by Jenkins and Hoyer (2000) also investigated the effect of aging and transfer, but using an enumeration task. During the training phase of this task, young and older adults needed to determine the number of items in visual displays of 6 to 11 targets. During the transfer phase of this task, the targets in the visual displays were changed in identity and/or location. This change of targets (stimuli) in the transfer phase meant that participants could not rely on past instances from the training phase to perform the task, but had to rely instead on the execution of algorithms or procedural learning. The results indicated that performance was greatly impaired for both age groups in the transfer phase, especially when both the identity and location of targets was changed. This suggests that young and older adults did not learn the displays with procedural learning. Instead, they learned the displays by associating the numerosities with the target identities and/or locations, and storing these associations as instances in memory. The lack of age differences in the transfer phase implies that both age groups relied on item-specific learning to the same extent. This indicates that older adults are just as capable of item-specific learning as younger adults. The results from this study are consistent with those of a similar study by Lassaline and Logan (1993).

Finally, a study mentioned earlier, by Touron et al. (2001) involved young and older adults producing or verifying solutions to alphabet arithmetic problems. During the training phase of these tasks, participants were given 20 blocks of 30 trials, with arithmetic problems repeated in a random order. During the transfer phase of these tasks, participants were again given 20 blocks of 30 trials, but with a new set of arithmetic problems. The results were that both age groups displayed partial transfer to the new set of problems, with young adults being significantly faster than older adults. This again supports Anderson's ACT* theory in that participants acquired both item-general and item-specific productions in the training phase, but were only able to use the item-general productions (initially) in the transfer phase. The finding that younger adults were not as impaired initially as the older adults in the transfer phase suggests that younger adults relied more on general learning during training whereas older adults relied more on specific learning.

Thus, it seems that both young and older adults engage in a combination of general and specific learning during skill acquisition. However, the literature on aging and transfer has provided mixed results about the extent to which each age group relies on which type of learning. For example, some studies have found that older adults rely more on specific learning while younger adults rely more on general learning, while other studies have found the opposite pattern of results. Therefore, further research must be conducted in this area in order to clarify this issue.

Anxiety and Skill Acquisition

Anxiety can be described as "a state of strong concern or apprehension … [with] physical manifestations such as sweating, trembling, and palpitation " (University of Chicago, 1980, p. 434). It usually occurs when people are facing stressful or threatening situations. The automatic physiological response that is triggered in these situations is called the 'flight or fight' response, because it allows people to either protect themselves or escape from their source of stress (Andrews, Crino, Hunt, Lampe, & Page, 1994). Thus, anxiety is a normal and useful reaction that has been genetically passed down for the survival of the species.

However, Yerkes and Dodson (1908) discovered that too much anxiety is a disadvantage when performing or learning a task. They trained rats to escape an electric shock by turning small wheels in their cages, and found that the rats performed best under moderate electric shock conditions, and worse under low and high electric shock conditions. Thus, the performance of rats under different levels of arousal followed an inverted U-shaped function, which they called the 'Yerkes-Dodson Law' (Tomporowski, 2003). This phenomenon has been studied extensively over the years, and seems to describe performance in humans as well. That is, initially performance on a task improves as the individual becomes more anxious. As anxiety increases, performance improves until it reaches an optimum level and plateaus. With excessive anxiety, the individual's performance suffers and returns to baseline levels.

Wells and Matthews (1994) explained why high anxiety hindered performance by suggesting that it affects the cognitive functioning of the individual. Firstly, anxiety causes the individual to shift their attention to the perceived threat, thus reducing their ability to attend to and respond to the environment. Secondly, anxiety causes a narrowing of attention such that the individual focuses on parts of the situation rather than the whole situation. And thirdly, high anxiety often leads to changes in behaviour such as withdrawal and total disengagement. As a result, the individual finds it harder to perform complex cognitive and perceptual tasks (Mathews, 1990; Mathews & MacLeod, 1985). For example, many studies have found that anxiety impairs performance in tasks like mental arithmetic (Ashcraft, 2002; Ashcraft & Faust, 1994; Hopko, McNeil, Lejuez, Ashcraft, Eifert, & Riel, 2003; Kellogg, Hopko & Ashcraft, 1999), analogical reasoning (Tohill & Holyoak, 2000), verbal reasoning (Markham & Darke, 1991), geometrical analogies (Leon, 1989) and grammatical reasoning (MacLeod & Donnellan, 1993). Individuals that are highly anxious usually perform slower and less accurately on these tasks compared to individuals that are mildly anxious (Leon & Revelle, 1985).

State and Trait Anxiety

According to Spielberger, Gorsuch, Lushene, Vagg and Jacobs (1983), there are two forms of anxiety, called 'state anxiety' and 'trait anxiety'. State anxiety refers to an emotional state that exists at a particular moment in time and is transitory in nature (Spielberger, 1972). The characteristics of this state include subjective feelings of tension, apprehension and nervousness in response to stressful situations.

In contrast, trait anxiety is a stable and enduring personality trait that defines how prone an individual is to being anxious. That is, trait anxiety explains why some individuals interpret situations as dangerous and threatening (thereby increasing their state anxiety reactions) while other individuals interpret these same situations as less threatening. As a result, individuals with high trait anxiety will experience state anxiety reactions more frequently and more intensely compared to individuals with low trait anxiety (Spielberger et al., 1983).

Several research studies have been conducted using the constructs of state and trait anxiety. For example, Leon and Revelle (1985) studied the performance of subjects on an analogical reasoning task. The state and trait anxiety of subjects was measured using the Spielberger State-Trait Anxiety Inventory (Spielberger et al., 1983). A median split methodology was used to divide subjects as high or low trait-anxious, and high or low state-anxious. The results indicated that subjects with high state-anxiety were slower and less accurate than subjects with low state-anxiety. However, differences in trait anxiety did not seem to affect the performance of subjects. The investigators did not find this outcome surprising. Their explanation is that state anxiety affects performance because this is the anxiety that is actually experienced during the task. On the other hand, trait anxiety only represents the potential to experience anxiety during the task. Therefore, the investigators concluded that state anxiety must always be measured during skill acquisition experiments.

The importance of measuring state anxiety was highlighted in another study by Mahar, Henderson and Deane (1997). They asked 229 students to fill out the state anxiety scale of the Spielberger State-Trait Anxiety Inventory (Spielberger et al., 1983), as well as computer anxiety measures. Subjects were then required to perform a basic computing task involving data entry. The results indicated that state anxiety was strongly associated with performance on the computer task, with higher anxiety related to slower performance.

A different study by Harris and Cumming (2003) investigated the relationship between state anxiety, trait anxiety and a prospective memory task. Prospective memory refers to the ability to remember things in the future (e.g., remembering to attend appointments or put the bin out). In this study, 63 subjects were allocated to a high, medium or low anxiety group, based on their scores on the Spielberger State-Trait Anxiety Inventory (Spielberger et al., 1983). They were then given a prospective memory task, embedded within a semantic association task. The results indicated that individuals with high levels of state anxiety performed more poorly on the task than individuals with low levels of state anxiety. Trait anxiety scores, however, had no association with performance on this task. These results imply that state anxiety has a greater effect on task performance than trait anxiety, and should therefore always be measured in skill acquisition experiments.

On the other hand, several studies have also found links between trait anxiety and performance. For example, MacLeod and Donnellan (1993) asked 600 subjects to complete the trait section of the Spielberger State-Trait Anxiety Inventory (Spielberger et al., 1983). Those subjects who scored between 25 and 35 on the trait scale became the 'low anxiety' group, while those subjects who scored between 45 and 55 on the trait scale became the 'high anxiety' group. When subjects were asked to perform a grammatical reasoning task, the researchers found that individuals with high trait anxiety performed less well than individuals with low trait anxiety.

In another study by Zarantonello, Slaymaker, Johnson and Petzel (1984), subjects were assessed for trait anxiety using the Spielberger State-Trait Anxiety

Inventory (Spielberger et al., 1983). Subjects with a raw score of at least 45 on the trait scale were classed as 'anxious', while subjects with a raw score of 39 or below on the trait scale were classed as 'controls'. The results indicated that subjects who were anxious (as measured by the trait anxiety scale) obtained a lower accuracy level in the anagram tasks than control subjects. Thus, trait anxiety does seem to have an impact on the performance of subjects, and as such it should also be measured in skill acquisition experiments.

In summary, it seems that individuals with high state or trait anxiety are disadvantaged when performing tasks. However, it is often difficult to determine whether the performance characteristics of an individual are due to the individual's trait anxiety, state anxiety, or both. Indeed, the correlation between state anxiety measures and trait anxiety measures is high (.70), so it is difficult to determine their individual effects on performance (Spielberger et al., 1983). For this reason, both state anxiety and trait anxiety should be measured when conducting experiments on skill acquisition.

Trait Anxiety and Aging

It is conceivable that adults become more anxious as they get older (i.e., their trait anxiety becomes higher) because life becomes more stressful. For example, older adults face stressors such as retirement, children leaving home, widowhood, the loss of loved ones, frailty, failing health, and death (Schulz & Ewen, 1993). However, the opposite hypothesis is just as valid. That is, younger adults can face just as many stressful events as older adults, but they are just different stressful events. For example, younger adults face work issues, getting married, raising children, buying a home, moving house, relationship problems, and so on. Moreover, younger adults often do not have the confidence or maturity to deal successfully with stressful situations, whereas older adults have learned coping strategies from a lifetime of experience (Schulz & Ewen, 1993).

The small amount of research conducted in this area seems to support the second hypothesis: that older adults experience less anxiety, and are better able to cope with stressful situations compared to younger adults. That is, trait anxiety seems to decrease with age.

In a cross-sectional study by Nakazato and Shimonaka (1989), the Spielberger State-Trait Anxiety Inventory (Spielberger et al., 1983) was administered to 1,234 individuals aged between 25 and 92 years. The results indicated that both state and trait anxiety decreased linearly across the age groups. In fact, anxiety was lowest in the oldest age group.

In another study by Henderson, Jorm, Korten, Jacomb, Christensen and Rodgers (1998), the prevalence rate of anxiety was examined across the adult lifespan. Their sample of 2725 people consisted of people aged 18 to 79 years. All participants were asked to complete inventories for symptoms of depression, anxiety and other psychological phenomena. The results were that symptoms of anxiety declined significantly with age for women. The frequency of adverse life events also declined significantly with age. The results suggest that older adults experience fewer negative life events, and are generally less anxious than younger adults.

Other studies (e.g., Bergdahl & Bergdahl, 2002; Christensen, Jorm, Mackinnon, Korten, Jacomb, Henderson, & Rodgers, 1999; Fuentes & Cox, 2000; Palmore, Cleveland, Nowlin, Ramm & Siegler, 1979) have also supported these findings, with results indicating that there is either no change in anxiety symptoms with age, or a decline in anxiety symptoms with age. However, the results from these studies are based on cross-sectional data and should be interpreted with caution, since age group differences could be due to cohort effects rather than aging effects. Longitudinal studies are therefore required to verify these findings.

Studies have also investigated the prevalence of major anxiety disorders and subthreshold anxiety disorders in the elderly. Subthreshold disorders are those that do not meet the criteria for major disorders, according to guidelines such as the Diagnostic and Statistical Manual For Mental Disorders IV (American Psychiatric Association, 1999). Heun, Papassotiropoulos and Ptok (2000) performed a psychiatric assessment on 286 adults aged 60 years and over, and found that 6.6% of participants had a major anxiety disorder, while 18.5% had a subthreshold anxiety disorder. Similar results have been found in other studies (e.g., Forsell and Winblad, 1998; Mehta, Simonsick, Penninx, Schulz, Rubin, Satterfield, & Yaffe, 2003). Moreover, a study by Krasucki, Howard and Mann (1998) has found that the prevalence of major anxiety disorders (e.g., phobias, obsessive-compulsive disorder, panic disorder) actually decreases from age 65 onwards, so that it is lowest in the oldest age groups.

These prevalence rates for major and subthreshold anxiety disorders in the elderly seem to be slightly lower than those for younger adults (Kogan, Edelstein & McKee, 2000). For example, a review by Jorm (2000) looked at studies that examined the prevalence of anxiety disorders and symptoms across the adult life span. In order to be included for the review, studies needed to use a population sample that ranged from 30 to 65 years and over, and studies needed to use the same assessment tools for age groups. The results indicated that no consistent relationship existed between anxiety disorders or symptoms, and age. However, when risk factors (e.g., marital status, level of education, income etc.) were statistically controlled for, a consistent pattern emerged, whereby a decrease in anxiety disorders and symptoms occurred with age. Again, these results must be interpreted with caution, since the studies used in the review were cross-sectional in design.

Finally, a study by Coolidge, Segal, Hook and Stewart (2000) investigated the coping strategies of young versus older adults. The results revealed a low prevalence of anxiety symptoms in both young and older adults. Moreover, the older anxious adults used more effective coping strategies compared to the younger anxious adults, possibly due to the experience and wisdom that accumulates with age. Other studies have also shown that older adults do not show significant personality changes or increased maladjustment after stressful life events, suggesting that they have good coping mechanisms (Chiriboga & Dean, 1978; Costa, McCrae, & Arenberg, 1980).

In conclusion, older adults seem to be equally prone or less prone to anxiety symptoms and disorders compared to younger adults. That is, older adults seem to have the same or lower levels of trait anxiety compared to younger adults. Jorm (2000) proposed three factors that could account for this finding. Firstly, older adults may exhibit decreased emotional responsiveness due to age-related changes in their nervous systems. That is, older adults may simply respond less to negative emotions compared to younger adults. Secondly, older adults may possess increased emotional control, such that they are better at ignoring negative emotions and enhancing positive emotions, compared to younger adults. Thirdly, older adults may be psychologically immune to negative life events. That is, older adults are more resistant to negative life events compared to younger adults, because of the repeated exposure of such events in their lifetimes. Other explanations have also been offered to explain the lower trait anxiety with age. For example, older adults may become more psychologically stable with age, and become better able to cope with negative life events due to their life experiences (Nakazato & Shimonaka, 1989).

State Anxiety and Aging

Although trait anxiety seems to decrease across the adult lifespan, state anxiety might actually be higher in older adults compared to younger adults, especially during testing conditions. Schulz and Ewen (1993) suggest several possible reasons for this. Firstly, older adults usually have less years of education than younger adults, such that older adults may be less familiar with test requirements. Secondly, the lower years of education of older adults implies that they have less experience with examinations, and are more likely to feel anxious in test situations. Thirdly, older adults are less able to use strategies during tests, such as guessing freely when no penalty is given. Fourthly, older adults are often worried about becoming senile, and become anxious that their test scores will reveal this (Whitbourne, 1976). Therefore, older adults with high trait anxiety may experience intense state anxiety reactions when they are in test situations.

To investigate this possibility, Hill and Vandervoort (1992) assessed the state anxiety and free recall of adults who were aged 60 years and over. State anxiety was measured with the Spielberger State-Trait Anxiety Inventory (Spielberger et al., 1983). The investigators found that state anxiety and age were negatively associated with free recall scores. That is, the greater the state anxiety or the person's age, the worse their recall scores were. However, the relationship between age and state anxiety itself was not directly tested.

Other studies have focussed more on the effect of age on state anxiety during test conditions. For example, Fisk and Warr (1996) asked young and older adults to complete a state anxiety scale before they performed a computer-based associative learning task. The results were that older adults were significantly slower in acquiring the associations compared to younger adults. However, there were no age differences in state anxiety, and the statistical analyses found that state anxiety did not have a significant effect on performance in this task. The investigators attributed the age differences to other factors, such as the high levels of arousal and the low levels of self-efficacy in older adults.

Charness, Schumann and Boritz (1992) also conducted an experiment in which the computer anxiety of young and older adults was measured, before they performed a simple word-processing task. To measure the anxiety that subjects might have about computers, the investigators administered the Computer Anxiety Scale (or COMPAS) both before and after subjects performed the task. The results were that the older adults performed the task more slowly and with more errors compared to the younger adults. Furthermore, computer anxiety decreased for both age groups following completion of the task. However, anxiety was not significantly associated with the task performance in either age group. This suggests that anxiety is not the primary cause for the age-related differences in the test condition.

The results from these studies suggest that state anxiety is not significantly higher in older adults than in younger adults. Therefore, age differences in skill acquisition and transfer are probably not due to differences in state anxiety. However, the fact that higher levels of state anxiety are associated with impaired performance in many tasks indicates that state anxiety should still be measured in experiments as a precautionary measure.

Conclusions

In conclusion, the topics of skill acquisition, transfer and learning are relevant to all age groups. Indeed, people of all ages have been shown to learn new skills with practice, and their performance usually follows a power function or an exponential function when plotted against practice. The process of learning seems to involve a shift from slow and effortful performance to a fast, effortless and automatic performance. This shift in performance has been described in detail by Anderson's ACT* Theory and Logan's Instance Theory.

The research on aging and skill acquisition suggests that older adults are capable of learning motor, perceptual, cognitive and implicit skills. However, older adults are often slower at acquiring these new skills compared to younger adults, and often make more errors than younger adults. This could be due to the physical changes that occur in the body with age, including changes in vision, the brain and the nervous system (see Chapter 1). These physical changes could in turn affect the speed of information processing and the functioning of working memory with age. However, the plasticity of the human brain might explain why older adults are still capable of acquiring new skills, although the performance of these skills might be inferior compared to that of younger adults.

In terms of skill transfer, many studies have found that subjects partially retain some of the general skills learned during training. Anderson's ACT* theory seems better able to explain this transfer of both general and specific skills compared to Logan's Instance Theory. The literature on aging and transfer also suggests that older adults often show partial transfer, implying that they are able to learn a combination of general and specific skills during training. However, the extent to which they engage in each type of learning compared to young adults remains unclear.

Finally, research on anxiety suggests that individuals with high state or trait anxiety may perform less well than individuals with low state or trait anxiety. Studies have generally found that older adults are less anxious than younger adults and thus have lower levels of trait anxiety. Studies have also shown negligible age differences in state anxiety during test conditions. However, many studies have shown that high levels of state or trait anxiety are detrimental to task performance in young as well as older adults. Therefore, the administration of state and trait anxiety measures to subjects is a crucial part of any skill acquisition study.

Chapter 3: Working Memory

Working memory is a theoretical construct that forms part of a larger theory of memory. It functions as a limited-capacity system that allows information to be temporarily stored and processed during cognitive activities (Richardson, 1996). According to Miyake and Shah (1999), it is "... involved in the control, regulation, and active maintenance of task-relevant information in the service of complex cognition" (p. 450).

Many researchers have proposed that individual differences in working memory capacity are related to individual differences in how well people learn and perform skills (e.g., Kyllonen, 1986; Kyllonen & Christal, 1987). For example, Kyllonen and Christal (1990) studied the relationship between reasoning ability and working memory capacity by asking 2000 participants to complete a variety of psychometric tests. The psychometric tests measuring reasoning ability included arithmetic reasoning, grammatical reasoning, verbal analogies and syllogisms. The psychometric tests measuring working memory capacity included digit span, mental arithmetic and alphabet recoding. Analysis of the data revealed that there was a consistently high correlation (r = .80 to .90) between working memory tests and reasoning ability tests. This suggests that adults with higher working memory spans were able to obtain higher scores in reasoning ability, and vice versa. Thus, working memory capacity was related to the performance of adults in reasoning skills.

However, working memory also seems to play an important role in the learning of skills. For example, Woltz (1988) investigated the role of working memory when learning a procedural task. The task involved taking different actions under different conditions on a computer. Working memory was assessed using a number of psychometric measures. The results were that working memory capacity predicted performance in the early stages of skill acquisition. That is, the greater the working memory capacity, the better the performance during early skill acquisition. This finding supports Anderson's ACT* (1982) theory of skill acquisition, in which working memory is essential for the early stages of learning, to maintain and interpret declarative knowledge about the skill. However, with practice the declarative knowledge is converted into procedural knowledge, which does not place high demands on working memory. As a consequence, performance on the task becomes fast and automatic in the later stages of skill acquisition.

Another study by Logie, Baddeley, Mane, Donchin and Sheptak (1988) also investigated the role of working memory in the acquisition of a complex cognitive skill. The skill consisted of learning a complex computer game called 'Space Fortress', whereby participants needed to monitor events, make strategic decisions, manage their response times, and monitor their accuracy. The investigators found that when the general working memory load was increased (by asking participants to perform a secondary task concurrently with the main task), this had a detrimental effect on many components of task performance. The investigators thought that performing a concurrent secondary task probably placed too much load on the limited-capacity working memory, such that performance in the primary task became impaired. This result indicates that working memory capacity can determine the extent of skill acquisition in individuals.

Moreover, some studies have found that age-related differences in working memory can account for age group differences in declarative learning (e.g., Kirasic, Allen, Dobson, & Binder, 1996) and procedural learning (e.g., Morrell & Park, 1993). Therefore, it seems that individual differences in working memory can account for individual differences in learning and performing skills, as well as individual differences in intellectual ability and fluid reasoning (Kyllonen, 1986; Kyllonen & Christal, 1990; Sternberg, 1980; Wechsler, 1997). The relevance of working memory to the current issue of skill acquisition is clear. A detailed discussion of the working memory concept follows.

Atkinson and Shiffrin's Model of Memory

The concept of working memory first emerged in Atkinson and Shiffrin's (1968) model of memory. They proposed a multi-stage model whereby sensory information from the environment enters through our sensory registers and is temporarily stored in short-term memory. However, it was believed that short-term memory had only a limited capacity for storing information. Therefore, Atkinson and Shiffrin (1968) suggested that information was rehearsed in short-term memory and transferred into a long-term memory, which had an unlimited storage capacity and could store information permanently. Thus, Atkinson and Shiffrin (1968) believed that short-term memory was "the subject's working memory" (p. 90) in that it allowed individuals to process and store information that was relevant to the task at hand. However, Atkinson and Shiffrin (1968) did not expand further on this point.

Atkinson and Shiffrin's (1968) model of memory received some support from empirical studies. For example, Iversen (1977) reported that the short-term memory functions of amnesic patients could be intact even when their long-term memory functions were impaired. This gave credence to the notion that humans possessed two types of memory, which had different anatomical locations in the brain (Andrade, 2001). Having two types of memory might also explain the tendency of subjects to recall the last items in a word list during free recall, as opposed to the first or middle items of this list. This 'recency effect' has been observed in several studies (e.g., Glanzer & Cunitz, 1966; Murdock, 1962). Atkinson and Shiffrin (1968) explained this phenomenon by proposing that the last items on a word list are still in short-term memory storage when the subjects are tested, and as such they can be quickly and easily retrieved.

However, empirical research has also found problems with Atkinson and Shiffrin's (1968) model of memory. For example, Craik and Watkins (1973) investigated the role of rehearsal in transferring items from short-term memory to long-term memory. They tested the hypothesis that the more an item is rehearsed, the more likely it is to be recalled later on. In their experiment, subjects were verbally presented with a list of words and asked to remember the last word in the list that started with a particular letter (e.g., the letter 'g'). Therefore, it was assumed that words starting with the letter 'g' were rehearsed more than words not starting with the letter 'g' in the list. When subjects were given a surprise test in which they had to recall as many words from the list as possible (even those not starting with 'g'), the most rehearsed words were not better remembered than the least rehearsed words. This suggests that rehearsal alone is not enough to transfer information from short-term storage to long-term storage.

Research on the recency effect (e.g., Bjork & Whitten, 1974; Tzeng, 1973) has also found that when subjects are asked to count backwards at the end of a word list, the recency effect disappears. However, when subjects are asked to count backwards after each word on the list, the recency effect appears again. This second counting task should disrupt the recall of recent items from the short-term memory store. The fact that memory retrieval is not disrupted from short-term memory suggests that the second counting task does not place any load on short-term memory, but places a load on a different processing mechanism instead. Some people have proposed that this other mechanism is something like a working memory.

Baddeley and Hitch's Model of Working Memory

Baddeley and Hitch (1974) were originally interested in the storage capacity of short-term memory. Thus, they conducted an experiment where subjects were asked to perform a digit span task at the same time as performing a comprehension, reasoning, or long-term memory task. Baddeley and Hitch thought that if the digit span task competed with a concurrent task for storage space in short-term memory, then an increase in digit span load would cause a decrease in the subject's performance on the concurrent task. However, the results showed that a three-digit load had no effect on language comprehension and only a minimal effect on long-term memory; a one- or two-digit load had no effect on logical reasoning; and a six-digit load had only a small effect on all three tasks. This suggested to Baddeley and Hitch that the digit span task was loading only one of a number of subsystems, leaving the other subsystems relatively free to deal with the other tasks.

Based on these findings, Baddeley and Hitch designed their model of working memory (Baddeley, 1986), which consisted of "modality-specific, limited-capacity storage components, or 'slave systems', subserving a limited-capacity general processor" (Andrade, 2001, p. 11). That is, they thought that a general processing system supervised and coordinated two subordinate 'slave systems' (Baddeley, 1998). The general processing system was named the 'central executive', the slave system responsible for manipulating speech-based information was named the 'articulatory loop' or the 'phonological loop', and the slave system responsible for manipulating visual information was named the 'visuo-spatial sketchpad' (Baddeley, 1998). Figure 1 shows a simplified version of the working memory model.

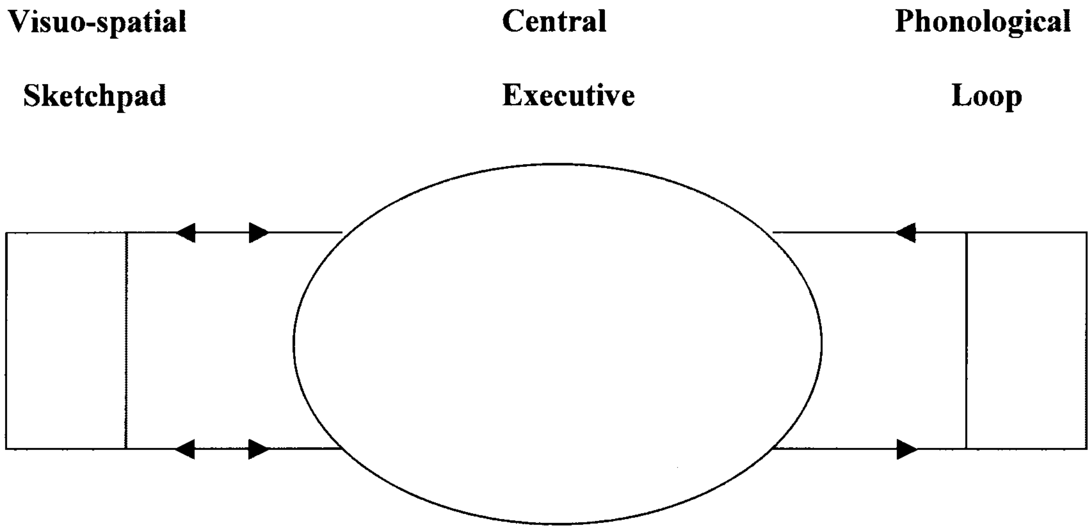

Figure 1. Baddeley and Hitch's working memory model. Adapted from Baddeley (1998).

The Phonological Loop

Baddeley (1998) describes the phonological loop as a system with a storage component (the 'phonological store') and a processing component (the 'articulatory control process'). The phonological store holds speech-based information for about one-and-a-half to two seconds at a time, after which the information fades and becomes unretrievable. However, if the information is read by the articulatory control process and refreshed through subvocal rehearsal, it can be fed back into the phonological store. The articulatory control process also accepts printed or visual information, as it converts the information into a phonological code and sends it to the phonological store (Baddeley, 1998).

Empirical evidence for the phonological loop comes from the 'phonological similarity effect' (Baddeley, 1998). This is a phenomenon whereby performance in immediate serial recall declines when the stimuli sound the same or have similar articulatory characteristics (Baddeley, 1966a; Conrad & Hull, 1964). The probable reason for this decline in performance is that the phonological store is actually based on phonological codes. Since similar-sounding items have similar phonological codes, it is harder to discriminate one from another, and recall therefore takes longer and is prone to errors (Baddeley, 1998).

Another line of evidence for the phonological loop comes from the 'unattended speech effect' (Baddeley, 1998). A study by Colle and Welsh (1976) found that when English-speaking subjects are asked to recall sequences of visually presented numbers, their performance declines when they hear German speech in the background. A different study by Salamé and Baddeley (1982) investigated whether digit span in subjects was affected by either a background of spoken digits, a background of words with the same phonemes as digits (e.g., *gun, moo* instead of *one, two*), a background of words with non-digit phonemes (e.g., *happy, tipple*), or a background of silence. The results were that words with the digit phonemes caused greater impairments in performance than words with non-digit phonemes. However, the impairment with words was about the same as for actual spoken digits. This was not an expected result, as actual digits were predicted to cause more interference than non-digits with the same phonemes. Salamé and Baddeley (1982) concluded that the unattended material was gaining access to the phonological store, and that the phonological store was holding phonological information about items rather than semantic information. Salamé and Baddeley (1987) conducted a further experiment to see whether any sound could enter the phonological store. Again, subjects were asked to recall sequences of digits against a background of unattended speech versus a background of unattended noise. The results were that unattended speech affected performance while unattended noise did not, even when the noise was pulsed to simulate the intensity of speech. This suggests that the phonological store is particularly sensitive to speech.

The 'word-length effect' has also provided support for the existence of a phonological loop in working memory (Baddeley, 1998). A study by Baddeley, Thomson and Buchanan (1975) found a direct relationship between word length, reading rate, and recall. The relationship suggested that long words take longer to read and longer to rehearse, thus impairing recall. Further evidence came from Ellis and Hennelly (1980). They discovered that the poorer performance of Welsh-speaking children on digit span and mental arithmetic was due to the Welsh digit names having longer vowel sounds and taking longer to say compared to English digit names. Indeed, when bilingual Welsh- and English-speaking subjects were tested with a digit span task, they performed worse in their native language of Welsh, but their digit spans were the same when measured in terms of speaking time. Later research by Naveh-Benjamin and Ayres (1986) also found definite relationships between memory span and the time taken to speak digits in different languages. These findings suggest that the longer the articulation times for words or digits, the longer the subvocal rehearsal times for these items. Since it takes longer to rehearse the items, they are not refreshed as often in the articulatory control process, and are more likely to fade away. According to Hoosain and Salili (1988), the average time for a memory trace to fade away or decay is two seconds. Thus, the decreased rate of refreshing and higher incidence of decay will cause a poorer recall of items from word or number lists.

More evidence for the phonological loop comes from the research on 'articulatory suppression' (Baddeley, 1998). In such research, subjects are asked to mentally or physically articulate an irrelevant sound while learning a list of items. For example, subjects may be asked to repeatedly say the word 'the' while performing a digit span task. The result is that performance on the digit span task declines, whether the digits are presented verbally or visually (Richardson & Baddeley, 1975). The probable explanation for this is that the repetition of an irrelevant sound takes over the articulatory control process, such that it is less able to rehearse any relevant information from the phonological store, and less able to convert visual information into phonological codes. Furthermore, irrelevant spoken sounds can have the same effect as unattended speech by gaining access to the phonological store (Baddeley, 1998). Other researchers (e.g., Parkin, 1988) have argued that articulatory suppression actually places demands on a person's attention and that this is why their performance worsens. Baddeley, Lewis and Vallar (1984) tested this theory by asking subjects to perform a secondary task that did not require verbal articulation but needed as much attention as articulation. They used a tapping task in which subjects were asked to tap at the same rate as that of articulatory suppression. Baddeley et al. (1984) found that such a task had little or no effect on immediate recall of items. This suggests that articulatory suppression puts a load on the phonological loop rather than on general attentional resources.

Research has also looked at how articulatory suppression affects the 'phonological similarity', the 'unattended speech' and the 'word length' phenomena. Several studies have found that articulatory suppression removes the phonological similarity effect when items are presented visually (e.g., Estes, 1973; Levy, 1971; Murray, 1968; Peterson & Johnson, 1971). This could be because articulatory suppression stops the process of subvocal rehearsal, which in turn stops the visual items from being converted into phonological codes for storage. Therefore, memory for these items will be based on a non-phonological store rather than a phonological one. However, the phonological similarity effect returns if items are presented verbally, presumably because the verbal information gains direct access to the phonological store and does not need recoding by the articulatory control process (Baddeley, 1986; Baddeley et al., 1984). The same reasoning can explain why articulatory suppression removes the unattended speech effect when items are presented visually (Salamé & Baddeley, 1982), but not when items are presented verbally (Hanley & Broadbent, 1987). Several studies have also found that articulatory suppression removes the word length effect for both visual and verbal items. This provides further evidence that articulatory suppression prevents the process of subvocal rehearsal from occurring (Baddeley, 1986; Baddeley et al., 1984).

The Visuo-Spatial Sketchpad

According to Baddeley (1986) there 'appears to be good evidence for the occurrence of a temporary visuospatial store ... that is capable of retaining and manipulating images" (p. 143). This visuospatial store has been referred to as the visuo-spatial sketchpad (VSSP).

One of the first studies to look at imagery and working memory came from Brooks (1967). His task involved showing subjects a 4 X 4 matrix, indicating which of the squares was the starting square, and then asking the subjects to memorise a sequence of sentences. The sentences used in the first condition of this experiment were "in the starting square put a 1, in the next square to the *left* put a 2, in the next square *up* put a 3 ..." and so on. Subjects were expected to memorise these sentences by visualising the locations of the numbers in the matrix. In the second condition of the experiment, subjects were encouraged to use a rote rehearsal strategy rather than a visual imagery strategy to memorise the sentences, by substituting the spatial adjectives *up-down* and *left-right* with non-spatial adjectives such as *good-bad* and *slow-quick*. Thus, the sequence of sentences to be memorised were of the form "in the starting square put a 1, in the next square to the *good* put a 2, in the next square to the *slow* put a 3 ..." and so on. The results were that subjects could recall eight of the spatial instructions, but only six of the non-spatial instructions. Brooks (1967) was also interested in whether the mode of sentence presentation (i.e., verbal vs visual) affected recall for those sentences. He found that recall was better when spatial instructions were presented verbally, and when non-spatial instructions were presented visually. He proposed that the spatial instructions are remembered using visual imagery. Therefore, when spatial instructions are presented visually, this interferes with the visual imagery process, and impairs performance. On the other hand, the non-spatial instructions are remembered using verbal rote rehearsal. Therefore, when non-spatial instructions are presented verbally (or auditorily), this interferes with the rote rehearsal process, and impairs performance. These results suggest the presence of a visual processing and storage component in working memory, in addition to a verbal processing and storage component.

The existence of multiple components in working memory has been further supported by Farmer, Berman, and Fletcher (1986). In their study, subjects were asked to perform either a verbal reasoning task or a spatial reasoning task. At the same time, subjects had to perform a secondary task, which consisted of either articulation (continually reciting the digits 1 to 4) or sequential spatial tapping. The results were that the concurrent articulation task interfered with the verbal reasoning task but not the spatial reasoning task. In contrast, the concurrent spatial tapping task interfered with the spatial reasoning task but not the verbal reasoning task. These findings imply that there are two separate slave systems in working memory.

Studies have also found that when a spatial task is performed concurrently with a visual task, performance on the visual task declines. For example, Barton, Matthews, Farmer and Belyavin (1995) asked subjects to store information from visual pattern displays while concurrently performing a spatial tapping task. The results were that the concurrent tapping task caused impairments in the short-term storage of simple visual patterns. That is, both tasks seemed to utilise something like the visuo-spatial sketchpad (VSSP) for maintenance and storage of information. In a similar experiment by Morris (1987), subjects were required to perform a visual imagery task while concurrently performing a spatial tracking task. Again, the concurrent spatial tracking task interfered significantly with their performance. An earlier study by Baddeley, Grant, Wight and Thomson (1975) required subjects to perform the Brooks spatial and verbal matrix tasks alone, as well as concurrently with a pursuit tracking task (i.e., keeping a stylus in contact with a light as it travelled along a circular track). The results were that the concurrent spatial tracking task interfered severely with the Brooks spatial matrix task (which used visual imagery), but not with the verbal version of the matrix task. The results from all these studies suggest that spatial tasks and visual imagery tasks impose a processing load on the same component of working memory.

Baddeley and Lieberman (1980) conducted a further study to determine whether the VSSP was essentially visual or spatial. Again, they used the Brooks matrix task (visual imagery condition), and combined it with a task that was either visual but not spatial, or spatial but not visual. The visual task involved judging the brightness of slides, while the spatial task involved tracking a pendulum (whilst blindfolded) and using only auditory clues. Baddeley and Lieberman believed that if the Brooks imagery task was mainly visual, then the task of judging slides would cause more interference. However, if the Brooks task was mainly spatial, then the task of auditory tracking would cause more interference. The results showed that the Brooks imagery task was disrupted most by the auditory tracking task. Thus, the Brooks imagery task seems to be based on spatial characteristics (such as localisation) rather than visual characteristics (such as brightness). However, later studies have found that brightness judgements do impair the performance of participants in the Brooks imagery task (Beech, 1984; Quinn, 1988), which suggests that the task involves both visual and spatial processes after all.

Research on visual imagery and verbal learning has also shed some light on the VSSP. It seems that the imageability of words (i.e., the ability of words to elicit a visual image), and instructing participants to use imagery when learning words and prose, has a significant positive effect on their recall performance (Baddeley, 1998). Paivio (1969) proposed that concrete words are better remembered than abstract words, because concrete words are imageable and can be represented both verbally and visually. To test this theory, Baddeley et al. (1975) asked participants to remember either imageable word pairs (e.g., bullet-gray) or abstract word pairs (e.g., gratitude-infinite) at the same time as performing a pursuit tracking task. Baddeley et al. (1975) expected that the imageable word pairs would be better remembered.

However, they also hypothesised that if the VSSP was involved in creating images for the imageable word pairs, then performing a concurrent tracking task should impair this process. As expected, the results were that imageable word pairs were much better recalled than abstract word pairs. However, the concurrent tracking task had only a small effect on the learning of imageable word pairs, and only a small effect on the learning of abstract pairs. Thus, Baddeley et al. (1975) concluded that the VSSP was not essential for the imageability effect to occur. However, a later study by Matthews (1983) found that a concurrent visual task (shape matching) did interfere significantly with the learning of concrete words, suggesting that the visual component of the VSSP was responsible for the imageability effect, rather than the spatial component.

Research has also been conducted on the 'unattended picture effect', which is equivalent to the 'unattended speech effect' in verbal memory (Baddeley, 1998). Logie (1986) asked participants to learn a list of words by using either imagery or rote rehearsal. At the same time, participants were asked to look at coloured patches on a computer screen, but to ignore what they saw. The results were that the unattended colour patches impaired performance in the imagery condition, but had no effect in the rote rehearsal condition. In another experiment, Logie (1986) again asked participants to learn a list of words by using either imagery or rote rehearsal. However, this time Logie (1986) used both an unattended picture condition and an unattended speech condition. In the unattended picture condition, participants were required to look at a screen with coloured patches while learning words, while in the unattended speech condition, participants heard their names being called out while learning the words. The results were that individuals using imagery to learn words were more impaired in the unattended pictures condition, while individuals using rote rehearsal to learn words were more impaired in the unattended speech condition. This dissociation suggests separate components in working memory for visual and verbal processing.

The 'visual similarity effect', which is analogous to the 'phonological similarity effect' in verbal memory, has also been studied widely. For example, Hitch, Halliday, Schaafstal and Schraagen (1988) found that young children were worse at recalling visually similar items than they were at recalling visually dissimilar items. Similarly, Hitch, Woodin and Baker (1991) found that older children and adults had more difficulty in recalling visually similar items if they were prevented from verbally recoding these items. Moreover, Hue and Ericsson (1988) found that individuals had trouble remembering visually similar items when the items were novel (e.g., Chinese characters).

Research has also been conducted using 'concurrent articulation'. For example, Smyth, Pearson and Pendleton (1988) asked participants to remember sequences of movements or sequences of spatial locations in a Corsi blocks task. At the same time, participants were required to perform either another spatial task, or an articulation task. The result was that memory for movements or locations was impaired when individuals performed the concurrent spatial task, but not when individuals performed the concurrent articulation task. Similarly, Bruyer and Scailquin (1998) asked participants to perform mental imagery tasks while concurrently performing an articulation task. The result was that concurrent articulation did not interfere with the imagery tasks. These findings again imply that there are separate temporary storage systems for visuo-spatial and for verbal information.

In a different line of research, Kemps (1999) studied the effect of complexity on the recall of visuo-spatial information. Participants were asked to perform the Corsi blocks task under different levels of complexity, whereby complexity was manipulated by either increasing the number of blocks on the board, or by changing the positioning of blocks to random patterns. The results were that the recall of spatial locations worsened as the complexity of the visual stimuli increased. This finding implies that the VSSP has rehearsal constraints similar to the word length effect in verbal short-term memory.

In summary, research supports the notion of separate systems for processing and storing temporary visuo-spatial and verbal information. For example, concurrent visuo-spatial tasks have been shown to interfere with imagery learning (i.e., learning information by using imagery) but not rote learning (i.e., learning information by using rote rehearsal), while concurrent verbal tasks interfere with rote learning but not imagery learning. The finding that visually similar stimuli are not easily recalled also suggests that information is represented in the VSSP as a visual code. The unattended picture effect further implies that visual information gains automatic access to the VSSP, without the individual's knowledge. This is similar to what happens within the phonological loop (Quinn & McConnell, 1999). Andrade (2001) states that "visuo-spatial short-term memory appears to show effects of active interference (e.g., concurrent tracking tasks), passive interference (e.g., irrelevant pictures), complexity, and similarity that are analogous to the effects of articulatory suppression, irrelevant speech, word length and phonological similarity in verbal short-term memory" (p. 14). Thus, the VSSP seems to be very similar in its functioning to the phonological loop.

The Central Executive

According to Baddeley and Logie (1999), the central executive controls and regulates the working memory system. It has multiple functions, including "the coordination of the subsidiary memory systems, the control of encoding and retrieval strategies, the switching of attention, and the mental manipulation of material held in the slave systems" (Baddeley & Logie, 1999, p. 30). However, unlike the phonological loop and the VSSP, the central executive is not involved with the temporary storage of information.

Baddeley (1998) proposed that Norman and Shallice's (1986) 'supervisory activating system' or SAS model could explain the functioning of the central executive. According to Norman and Shallice, the mind contains well-known action programs or routines called 'schemata', which are used in familiar situations. These schemata are carried out in an automatic and reflex-like fashion. The schemata can be triggered by internal as well as external stimuli. If several conflicting schemata are triggered at the same time, a process called 'contention scheduling' allows the most appropriate or urgent schema to have priority by inhibiting the competing schemata. This automatic selection of action programs explains why it is hard to break old habits or learn new tasks. In order to change habitual behaviour, deal with novel tasks, or identify errors in behaviour, the 'supervisory attentional (or activating) system' must override contention scheduling by activating the weaker schemata and inhibiting the stronger schemata, thus influencing which schemata are selected (Andrade, 2001).

Norman and Shallice's (1986) model clarifies why action slips occur in everyday life. For example, a person making a cup of black coffee for a friend might habitually add some milk to the coffee. This action implies that the supervisory attentional system (SAS) has failed to override the habitual response that was selected by contention scheduling. Other evidence for the model comes from patients with frontal lobe damage, who tend to perseverate with certain action programs even when their task requires new action programs. Again, this probably occurs because the SAS has failed to override the person's habitual response (Baddeley, 1986; Baddeley & Wilson, 1988).

Additional evidence for the SAS model comes from studies on random generation. Baddeley (1966a) asked participants to generate random sequences of letters, but found that they repeated letters and used more stereotypical sequences of letters (such as ABC, MTV, HIV) when they were given less time to respond. Baddeley explained this by suggesting that the random generation of letters could only occur if the SAS constantly inhibited dominant schemata (i.e., sequences such as ABC and MTV) and constantly activated novel schemata. Therefore, when individuals are asked to do this task in less time, the demands placed on the limited-capacity SAS increase, and the SAS becomes less efficient as a result (Baddeley, 1986).

Further evidence for the central executive comes from patients with Alzheimer's Disease. Morris (1984) found that patients with mild dementia possessed poor verbal memory spans. However, this impairment was not caused by a malfunctioning phonological loop, since these individuals showed normal phonological similarity, word length and articulatory suppression effects. Therefore, Morris (1984) concluded that a malfunctioning central executive must be the cause of the impairment. The decreased central executive functioning in these patients may explain why they also have difficulty with random generation tasks (Baddeley, Bressi, Della Sala, Logie, & Spinnler, 1991; Brugger, Monsch, Salmon, & Butters, 1996).

Baddeley, Logie, Bressi, Della Sala and Spinnler (1986) also studied the performance of Alzheimer's Disease patients in verbal and visuo-spatial tasks, compared to the performance of normal elderly and young adults. The researchers were particularly interested in the central executive's role as coordinator of the phonological loop and the visuo-spatial sketchpad. When Baddeley et al. (1986) asked participants to perform a digit span task and spatial tracking task concurrently, they found that the Alzheimer's Disease patients had more difficulty performing the dual task compared to the normal young and older adults. Moreover, the amount of impairment in the dual task increased as the severity of the Alzheimer's Disease increased (Baddeley et al., 1991). Such dual task deficits have also been found in people with frontal lobe damage (Baddeley, 1996). These studies suggest that the central executive is required for performing two tasks concurrently. However, when the central executive is damaged (as in the case of Alzheimer's Disease patients or frontal lobe patients), or when the demands placed on it are too great, then the efficiency of the central executive diminishes, and neither task is processed in an optimal manner. According to Baddeley (1996), "the capacity to carry out two tasks simultaneously appears to be a candidate for one separable feature of executive function" (p. 14). However, there is still much research to be done on the other features of the central executive.

In conclusion, there has been much empirical research to support Baddeley and Hitch's (1990) model of working memory. A small amount of research has also been conducted on the effect of age on Baddeley and Hitch's model of working memory. The research that is available on this topic is discussed at length in the following section.

Aging and Working Memory

Most of the research on working memory and aging has conceptualised working memory as a general limited-capacity system rather than a system with three separate components (as in the Baddeley and Hitch model). Research with this general resource model has found that as people get older, there is a decrease in the amount of cognitive resources available to perform competing tasks (Phillips & Hamilton, 2001). Moreover, aging is associated with a decline in information processing, presumably due to a decrease in the attentional capacity and processing speed of older adults (Salthouse, 1991). Salthouse (1992) strongly believes that the slower speed of processing in older adults accounts for their decrease in working memory capacity compared to younger adults. This hypothesis has been supported by numerous research studies using statistical partialling techniques (e.g., Chuah & Maybery, 1999; Kail & Salthouse, 1994; Salthouse, 1992).

In contrast, Baddeley and Hitch's working memory (WM) model has not been used so widely in research. However, the WM model provides a better understanding of the types of cognitive changes that occur with age, instead of basing all age differences on 'resource' differences (Phillips & Hamilton, 2001). Moreover, the literature on aging and working memory has provided inconsistent results in the past, possibly due to the different tasks that are used in various studies. According to Baddeley (1996), the WM model may be able to explain the inconsistent results that have been found in the past.

Aging and the Phonological Loop

The phonological loop has received little attention in aging research. However, a small number of studies have investigated the age differences in rate of articulation, which is closely related to the functioning of the phonological loop. Articulation rate refers to how long it takes to rehearse stimulus items using inner speech. Thus, articulation rate affects the number of items that can be rehearsed in a set amount of time, or how many times an item can be rehearsed, which in turn affects memory span. According to Kynette, Kemper, Norman and Cheung (1990), it is likely that older adults have slower articulation rates, which can cause a decreased functioning in verbal short-term memory as well as language processing. A study by Gerhand (1994, cited in Phillips & Hamilton, 2001) found that older adults performed more poorly than younger adults on a digit span task. However, when the variance due to articulation rate was statistically removed, the age differences disappeared. Therefore, the impaired performance of older adults can be explained in terms of a slower articulation rate rather than an impaired working memory. This slower articulation rate could be part of the more general decrease in information processing speed that occurs with age (Chuah & Maybery, 1999; Kail, 1993; Smyth & Scholey, 1996).

Research on the phonological loop has also focussed on the 'unattended speech effect', where the presentation of irrelevant background speech interferes with the performance of participants in verbal tasks (Salamé & Baddeley, 1982). A study by Rouleau and Belleville (1996) investigated this phenomenon with young and older adults. They asked participants to perform a digit span task with irrelevant speech in the background. The results showed a general age effect, with older adults recalling fewer digits than younger adults. However, there was no interaction between age and irrelevant speech, suggesting that older adults were just as capable at ignoring irrelevant background noise as younger adults.

Another line of research has focussed on 'concurrent articulatory suppression'. This is where participants are asked to repeatedly say a word (e.g., 'the') while performing a verbal task, so as to prevent the subvocal rehearsal of any verbal information. Gerhand (1994, cited in Phillips & Hamilton, 2001) used this methodology with young and older adults. He asked participants to perform a digit span task either with or without concurrent articulatory suppression. The results showed a general age effect with the digit span task alone. However, there were no age differences when digit span was performed with concurrent articulatory suppression. This suggests that the articulatory loop does not deteriorate with age. The general age effect found in the digit span task alone can be explained by older adults having slower articulation rates.

Aging and the Visuo-Spatial Sketchpad (VSSP)

Studies on aging and the VSSP have been conducted in a number of different ways. For example, in one study by Chagnon and McKelvie (1992) young and older adults were required to play a game of 'Concentration' in pictorial format. In this game, pairs of identical pictures are arranged randomly and arranged facedown on a grid. Each player then turns two pictures over at a time, and is allowed to keep the pictures if they match. However, if the pictures do not match, the player must return them in their places, and let the next player play. The winner of the game is the one with the most matching pairs, when the board is cleared. Thus, this game involves both visual memory (remembering the pictures) and spatial memory (remembering the locations of pictures). The results indicated that the older adults performed more poorly than the younger adults in this game, suggesting impairment in visuo-spatial memory with age.

Other studies investigating aging and the VSSP have utilised imagery tasks, since these tasks are thought to rely heavily on the VSSP. In one study by Cerella, Poon and Fozard (1981), young and older adults were asked to perform the imagery task of mental rotation. The results from the task indicated that older adults were slower and made more errors compared to younger adults. In another imagery study by Dror and Kosslyn (1994), young and older adults were asked to generate, scan, rotate or activate stored images. The results showed significant age differences for rotating and activating stored images, but minimal age differences for generating or scanning images. It is difficult to draw conclusions from this study, however, since it is likely that these tasks also used the central executive component of working memory (Phillips & Hamilton, 2001).

Some studies have investigated the VSSP by looking at the imageability of words. Paivio (1969) first proposed that concrete words are better remembered than abstract words, because concrete words are imageable and can be represented both verbally and visually. A study by Baddeley et al., (1975) found this advantage of concrete words over abstract words in young adults. Dirkx and Craik (1992) investigated this phenomenon with older adults, and found that they also remembered concrete (imageable) words better than abstract words. This suggests that both young and older adults use visual imagery to remember information. However, Dirkx and Craik hypothesised that older adults did not use visual imagery as efficiently as younger adults. They asked young and older adults to remember a word list under normal conditions, and also whilst performing a simultaneous visual task. The simultaneous visual task was used to prevent subjects from forming images of the words in their VSSP in that experimental condition. The results were that both age groups performed equally badly when asked to do the simultaneous visual task. However, when learning the word list by itself, the young adults remembered significantly more words than the older adults. This suggests that when there is the opportunity to use imagery, younger adults are more efficient at using imagery than older adults (Dirkx & Craik, 1992).

Further evidence for the decreased VSSP functioning in older adults comes from research on visual search. For example, Fisk and Rogers (1991) asked young and older adults to find target items amongst distractor items on a computer screen. In one condition (consistent mapping condition), the target items always appeared as targets and never as distractors, while in the other condition (variable mapping condition), target items sometimes appeared as targets and sometimes as distractors. While both age groups performed poorly in the variable mapping condition, the older adults were significantly worse than the younger adults in the consistent mapping condition, where performance was expected to become fast and automatic. This suggests that the functioning of the VSSP in older adults was impaired compared to that of younger adults.

More recent studies have looked at the role of visual processing in visual working memory. For example, Faubert (2002) and Faubert and Bellefeuille (2002) discussed experiments that look at visual processing and the VSSP. In one experiment, young and older adults were required to detect, discriminate and store information about different object sizes. In another experiment, young and older adults were required to store spatial frequency information while being presented with inter-stimulus masks. Both of these studies found no age-related differences in the processing or storing of low-level visuo-spatial information. However, Faubert

(2002) predicted that age differences would become apparent with increasingly complex visuo-spatial stimuli.

This was the finding in a study by Fahle and Daum (1997). In this experiment, young and older adults were asked to perform two visual memory tests. The first test consisted of simple visual material, while the second test consisted of complex visual material. In the first test, participants were presented with a vernier stimulus on a computer screen, with an offset of 80, 120 or 240 arcsec. After a delay of 1 or 4 seconds, another vernier stimulus appeared on the screen, with either a larger or smaller offset than the first stimulus (thereby giving it a different appearance to the first stimulus). Participants were required to determine whether the offset of the second stimulus was larger or smaller than that of the first stimulus. The results indicated no age-related differences in performance of this simple visual test. In the second test, participants were presented with complex pictures of geometrical figures (i.e., made up of shapes in certain spatial configurations) for 10 seconds at a time. After each presentation, participants were required to draw the pictures from memory. The pictures that were presented varied in their complexity. The results were that age-related differences occurred in this task, with older adults making more errors than younger adults. The investigators concluded that visual short-term memory remains intact with age for basic visual information, but becomes impaired with age for complex visual information.

Aging and the Central Executive

According to Baddeley (1986), the central executive component of working memory deteriorates significantly with age. Many research studies investigating the central executive have supported this claim. For example, Morris and Jones (1990) proposed that central executive functioning could be studied by giving participants 'keeping-track' tasks in which they need to constantly update their memory. Dobbs and Rule (1989) found that when young and older adults were given such a task, the older adults found it harder to keep track of information than the younger adults.

Researchers have also investigated the central executive by assuming that it functions like the supervisory attentional system (SAS) model proposed by Norman and Shallice (1986). According to this model, the central executive is responsible for the planning and monitoring of single action programs or routines called 'schemata', as well as inhibiting inappropriate or competing schemata. Random generation tasks have been used to test these functions of the central executive. These tasks require participants to randomly generate sequences of numbers, letters or tapping responses, while avoiding stereotypic responses such as 'ABC' or '123'. According to Baddeley (1986), the generation of random responses means that automatic stereotypic responses need to be actively inhibited, which places an increased load on the central executive. The research conducted on random generation has found that older adults are less able to produce random number sequences than younger adults (Van der Linden, Bregart, & Beerten, 1994) and less able to produce random tapping sequences than younger adults (Phillips, Gilhooly, Logie, Della Sala, & Wynn, 2001). These results suggest that the central executive is less effective in older adults than younger adults, because it is less able to inhibit automatic stereotypic responses. However, it is also possible that the older adults have a poorer understanding of the requirements of tasks. Therefore, solid conclusions about how the central executive functions with age cannot be made from this particular research.

On the other hand, neuropsychological research has supported the notion that the central executive becomes impaired with age. In neuropsychology, the central executive seems to be closely linked to the frontal lobes of the brain (Moscovitch, 1994; Parkin, 1997; West, 1996). Many research studies have found that with age, the frontal lobes deteriorate earlier and quicker than any other areas of the brain (Coffey, Wilkinson, Parashos, Soady, Sullivan, Patterson, Figiel, Webb, Spritzer, & Djang, 1992; Coleman & Flood, 1987; Raz, Gunning, Head, Dupuis, & Acker, 1998).

Moreover, studies that use neuropsychological tests to assess executive function (e.g., the Wisconsin Card Sorting Test, verbal fluency, self-ordered pointing, and the Stroop Test) have found that older adults perform more poorly compared to younger adults (e.g., Rabbit, 1997; Rogers & Fisk, 1991; Shimamura & Jurica, 1994). However, it has been suggested that older adults perform poorly on these tests not because of impaired executive function, but because of slower speed of information processing (Phillips, 1999; Uttl & Graf, 1997). For example, the Stroop test requires participants to read colour words that are printed in different colour inks. When the individual is asked to name the colour of the ink rather than the colour word, they must actively ignore the colour word and focus on the colour of the ink, in order to be accurate. Thus, the central executive is needed to inhibit the inappropriate and automatic response of naming the colour word rather than the ink. Since older adults are thought to have impaired central executive functioning, this explains why they perform the task more slowly than younger adults. However, another issue to consider is that ink naming involves more stages of information processing than simple colour word naming. That is, ink naming involves the inhibiting of the automatic response of reading the word, and activating the nondominant response of naming the colour (two steps) whereas colour word naming involves only the automatic response of reading the word (one step). Since older adults are believed to have a decreased speed of information processing compared to younger adults, this would explain why their performance is significantly slower than that of younger adults in the ink naming condition. Verhaeghen and De Meersman (1998) conducted a review of twenty studies on aging and the Stroop Test, and came to the conclusion that "the apparent age-sensitivity of the Stroop interference effect appears to be merely an artefact of general slowing" (p. 120).

Overall then, the evidence seems to suggest that the central executive does deteriorate with age. However, the research findings must be interpreted with caution, since age differences can also be due to older people not fully understanding task requirements, and older people being slower at information processing. Furthermore, it is difficult to determine whether the poorer performance of older adults is due to impaired executive functioning only, or whether impairments in the phonological loop or visuo-spatial sketchpad are also involved (Phillips & Hamilton, 2001).

Aging and the three components of Working Memory

Several research studies have investigated age differences in the different components of working memory, rather than focussing on just one component of working memory at a time. For example, Salthouse, Kausler and Saults (1988) asked young and older adults to perform a verbal memory and a spatial memory task using the same stimuli, but different modes of recall. The results were that older adults performed more poorly than younger adults on both tasks. While this suggests that the phonological loop and visuo-spatial sketchpad deteriorate to the same extent with age, the central executive may also have contributed to the impaired performance.

Thus, it is difficult to conclude which components have actually deteriorated with age from this study.

In a different study by Tubi and Calev (1989), young and older adults were presented with a series of geometric designs (a visuo-spatial task) or a series of words on cards (a verbal task), one at a time. After the presentation of the stimuli, participants were given an interference task in which they had to remember an 8-digit number. Following this, the recall ability of participants was tested. Individuals were given pieces of paper, and either asked to write as many words as they could remember from the original stimuli (verbal task condition), or to draw as many designs from the original stimuli (visuo-spatial task condition). These recall tests allowed the investigators to assess the verbal and visuo-spatial working memories of the participants. The results were that the older adults performed more poorly than the younger adults on both tasks. However, the older adults demonstrated greater impairments in visuo-spatial recall than in verbal recall, compared to the younger adults. These results imply that the visuo-spatial working memory declines to a greater extent with age than the verbal working memory. The investigators suggest two possible explanations for this. It could be that the right hemisphere deteriorates with age, thus causing impairments in visuo-spatial functioning. Alternatively, a lifetime of experience with verbal material might explain why verbal memory is more resistant to age-related decline compared to visuo-spatial memory.

A study by Feyereisen and Van Der Linden (1997) investigated the effects of aging on the phonological loop and the VSSP, by using dual task methodology. That is, they asked young and older adults to perform a verbal and a visuo-spatial task while concurrently performing an articulatory suppression or a pattern-tapping task. The investigators predicted that performing the concurrent articulatory suppression task should cause more interference to the verbal task than the visuo-spatial task, while performing the pattern-tapping task should cause more interference to the visuo-spatial task than the verbal task. The results supported these predictions. That is, both young and older adults were significantly impaired when performing the articulatory suppression task at the same time as the verbal task, or the pattern-tapping task at the same time as the visuo-spatial task, with older adults performing more poorly than younger adults. Impairments also occurred in the cross-modality conditions for both age groups, but to a much lesser extent. This pattern of results suggests that the phonological loop and the VSSP both become impaired with age. This study is at odds with other studies reporting that the phonological loop remains intact with age.

A different study by Dolman, Roy, Dimeck and Hall (2000) also investigated the effect of age on the VSSP and the phonological loop by giving young and older adults a number of span tasks. These tasks included the spatial span task and digit span task from the Wechsler Memory Scale Revised (Wechsler, 1987), a hand gesture task, and a visual design span task. The results were that older adults performed more poorly than younger adults in all tasks except for the digit span task, where performance was the same for both age groups. These results suggest that the VSSP deteriorates with age, whereas the phonological loop remains intact with age.

Jenkins, Myerson, Joerding and Hale (2000) also investigated age effects on verbal and visuo-spatial working memory. In this study, young and older adults were asked to perform verbal and visuo-spatial memory tasks either alone, or with a concurrent verbal or visuospatial secondary task. The primary verbal task was a letter span task, in which subjects had to recall series of letters. The primary visuo-spatial task was a location span task, in which subjects had to recall sequences of locations on a grid. The secondary tasks involved either naming the colour of a stimulus (verbal) or colour-matching stimuli on a screen (visuo-spatial). The results were that for both age groups, the verbal secondary task caused more interference to the letter span task than to the location span task, while the spatial secondary task caused more interference to the location span task than to the letter span task. This further supports the notion that there are two distinct subsystems in working memory, and that these subsystems remain distinctive throughout the adults lifespan. However, the investigators also found greater age differences in the location span task compared to the letter span task, with memory spans being generally lower for older adults. These results imply that there is a greater decline with age in visuo-spatial working memory, compared to verbal working memory.

A correlational study conducted by Fisk and Warr (1996) investigated the functioning of the phonological loop and the central executive with age. They asked subjects to perform a central executive task (random generation of letter sequences) as well as two phonological loop tasks (digit span and word span). The researchers also assessed working memory span by asking subjects to perform a computation span task and a reading span task, both of which involve simultaneous processing and storage of the working memory. The researchers then examined whether age differences in working memory span could be explained by the age differences in phonological loop or central executive functioning. An analysis involving hierarchical regression found that a partial correlation existed between central executive and working memory span measures, but no correlation existed between phonological loop and working memory span measures. This suggests that age decrements in working memory span can be explained partially by impaired central executive functioning, but not impaired phonological loop functioning. Fisk and

Warr (1996) also asked participants to perform simple perceptual comparison tasks to assess their processing speed. The results were that processing speed predicted age differences in working memory span. Fisk and Warr (1996) concluded that older adults have slower speeds of perception that negatively affect central executive functioning, and working memory span as a consequence.

Several studies have investigated the effects of aging on the phonological loop and the central executive, by experimentally manipulating verbal memory tasks (e.g., Craik, Morris, & Gick, 1990; Morris, Craik, & Gick, 1990). In these studies, the main verbal memory task used was the 'sentence span' task, where participants were asked to determine if a sentence made sense while simultaneously remembering a list of words. The complexity of the task was modified in two ways: storage complexity was increased by adding words to be remembered, and processing complexity was increased by enhancing the grammatical complexity of sentences. The investigators predicted that age differences in performance would not occur when increasing the storage complexity of the task, because the phonological loop is responsible for the storage of verbal information, and it is thought to remain intact with age. On the other hand, the investigators predicted that age differences in performance would occur when increasing the processing complexity of the task, because the central executive is responsible for processing information, and it is thought to deteriorate with age. The results supported the predictions, with older adults performing more poorly than younger adults in the increased 'processing' complexity condition, but not in the increased 'storage' complexity condition. This suggests that the phonological loop is not affected by age, whereas the central executive is.

A study by Coates, Sanderson, Hamilton and Heffernan (1999) investigated the functioning of the visuo-spatial sketchpad (VSSP) with age. To measure the visual component of the VSSP, participants were asked to remember abstract visual matrix patterns (the 'visual matrix task'), and to measure the spatial component of VSSP, participants were asked to remember sequences of spatial locations with the 'Corsi block' test. The results were that older adults performed more poorly than younger adults on both tasks. This suggests that both the visual and spatial components of VSSP deteriorate with age. However, there is no evidence that these two tasks tap exclusively into the components of the VSSP, and as such, the age differences could be due to impairments in other components of working memory, such as the phonological loop or the central executive.

To investigate this possibility, Hamilton, Coates and Heffernan (2003) asked young and older subjects to perform a verbal fluency task at the same time as performing the visual matrix task or the Corsi block task. The verbal fluency task required participants to randomly generate words with minimal repetitions, thus tapping into the central executive component of working memory. Hamilton et al. (2003) found that participants performed more poorly in both the visual and spatial task when asked to do the concurrent verbal fluency task, with older adults being more impaired in both tasks compared to younger adults. This indicates that the two tasks required central executive involvement, and that the load on the central executive became unmanageable when verbal fluency was performed concurrently, especially for the older adults. Several researchers have suggested ways in which the central executive might be involved in the visual and spatial tasks. For example, the visual matrix task may rely on the central executive to make visual 'chunks' of patterns and to actively rehearse pattern representations, while the Corsi block task may rely on the central executive to make representations of the sequential order of stimuli (Farand & Jones, 1996; Smyth & Scholey, 1996). Therefore, these studies suggest that both the VSSP and the central executive may deteriorate with age.

A different study by Phillips et al. (2001) examined the performance of 36 young and 36 older adults on the Tower of London (TOL) task and a range of concurrent tasks. The TOL task required the moving of coloured disks, one at a time, from one tower to another so as to achieve a goal state. This task is believed to measure central executive functioning (Shallice, 1982). The concurrent tasks included an articulatory suppression task (counting from 1 to 10 out loud) to load the phonological loop, a random generation task (verbally generating random sequences of digits) to load the phonological loop and central executive, a spatial pattern tapping task to load the VSSP, and a random spatial tapping task to load the VSSP and central executive (Baddeley, Emslie, Kolodny, & Duncan, 1998). The results were different for the young and older groups. For the young adults, TOL performance became significantly poorer when they performed the random generation task concurrently. For the older adults however, TOL performance became significantly poorer when they performed the articulatory suppression task, the pattern tapping task and the random tapping task concurrently. This suggests that all three components of working memory deteriorate with age. Another explanation is that older adults are generally less able to perform two cognitively demanding tasks at the same time, which suggests an impairment of the central executive or attentional system with age. Indeed, there is some evidence that older adults are impaired at coordinating multiple tasks, especially when the tasks are complex (McDowd & Craik, 1988) or require the constant switching of attention (Phillips & Hamilton, 2001).

Conclusions From Aging and Working Memory Research

The majority of studies have found that the phonological loop remains intact with age. There is evidence that older adults are just as capable as younger adults at ignoring irrelevant speech with verbal tasks. Moreover, older adults do not become more impaired than younger adults when performing concurrent articulatory suppression with verbal tasks. The finding that older adults perform more poorly than younger adults in digit span tasks can be attributed to the slower articulation rates of older adults rather than problems with their phonological loop.

On the other hand, there is a great deal of evidence to suggest that the VSSP deteriorates with age. For example, older adults perform more poorly than younger adults in the visuo-spatial memory game of Concentration, older adults are impaired in imagery tasks compared to younger adults, and older adults are less efficient at using imagery compared to younger adults. Studies have also found that older adults have more difficulty in visual search tasks compared to younger adults. Moreover, studies that have tested both the phonological loop and the VSSP using dual tasks have found that the phonological loop stays intact while the VSSP deteriorates with age. On the other hand, research focussing on the role of visual processing on the VSSP has found no age differences in the processing or storing of low-level visual-spatial information. Therefore, it may be that the VSSP remains intact with age for basic visual information, but deteriorates with age for complex visual information.

Finally, the empirical research suggests that the central executive deteriorates with age. There is evidence that older adults perform more poorly than younger adults in 'keeping track' tasks, random generation tasks and the Tower of London task. There is also neuropsychological evidence that the frontal lobes deteriorate with age, and that the performance of older adults is impaired in neuropsychological tests when compared to younger adults. Furthermore, studies using correlational methodology, or manipulating the storage and processing components of tasks, or using dual task methodology, have all found that the central executive becomes impaired with age. One general explanation for these results is that there is a decrease in the speed of information processing that occurs with age. This slowing down of information processing has a negative impact on the efficiency of the central executive, and on the whole of working memory as a consequence.

The finding that certain components of working memory remain intact with age while other components deteriorate is important, especially in relation to learning new skills. For example, older adults seem to be less efficient at learning new cognitive and perceptual skills compared to younger adults (see Chapter 2). The deterioration with age of the central executive and visuo-spatial processing areas of the brain may contribute to the age-related decline in these tasks (Lapidot, 1987). To investigate this further, the experiments described in Chapters 5 and 6 used tasks that tap into the different components of working memory. For example, a mental arithmetic task was used to investigate the functioning of the phonological loop and central executive with age, while a visual numerosity task was used to investigate the functioning of the phonological loop, the central executive and the visuo-spatial sketchpad with age. These tasks are described in more detail in Chapters 5 and 6.

Relationship Between Anxiety and Working Memory

As a final point, it has been suggested that anxiety reduces the functional capacity of working memory, and causes impairments in task performance as a consequence (Eysenck & Calvo, 1992; Liebert & Morris, 1967). Several studies have found that anxiety has a detrimental effect on working memory measures. For example, Idzikowski and Baddeley (1983) asked individuals to perform working memory tasks before giving a public talk. Participants demonstrated high levels of anxiety before the talk, as measured by physiological measures such as heart rate, and subjective accounts. The results were that performance in a digit span task decreased significantly from an average of 8 digits to an average of 7.25 digits. Furthermore, performance in a verbal fluency task also worsened with heightened anxiety. In this task, participants were asked to name as many words as possible starting with a certain letter of the alphabet. The average number of words for this task decreased from 22 words to 20 words under higher anxiety states.

In a subsequent study, Idzikowski and Baddeley (1987) asked novice parachutists to perform working memory tasks immediately before making their first jump. Again, the anxiety state of these individuals was high before the jump. The result was that performance was poorer in the digit span task and a letter-searching task under this high-anxiety condition. Several other studies have found that performance on digit span tasks is negatively affected by high anxiety states (e.g., Moldawsky & Moldawsky, 1952; Mueller, 1980).

Another line of research has been to study the effect of a particular type of anxiety, namely math anxiety, on working memory measures. Hopko, Ashcraft, Gute, Ruggiero and Lewis (1998) describe individuals with math anxiety as people who become physiologically aroused when presented with mathematical information, they have irrational beliefs about their ability to solve maths problems, they enrol in fewer maths courses, and avoid studying mathematics. Thus in many ways, mathematics anxiety is close to being a phobia, with individuals actively avoiding anything to do with maths. Individuals experiencing such high levels of math anxiety are expected to show impairments in their working memory functioning as a result, especially when performing a mathematical task.

To investigate this, Ashcraft and Kirk (2001) divided 66 individuals into high-math-anxious and low-math-anxious groups, depending on their scores on the short Mathematics Anxiety Rating Scale (sMARS). To measure working memory capacity, participants were given either a listening span task or a computation span task. In the listening span task, participants heard a number of sentences and answered a question about each sentence one at a time. At the end of a set, participants were asked to recall the last word of each sentence, in order. Thus, this task involved the processing of verbal information while simultaneously storing the last word of each sentence. In the computation span task, participants heard a number of simple arithmetic problems, and were asked to give an answer to each problem one at a time. At the end of the set, participants were required to recall the last number of each problem, in the order that it was presented. Therefore, this task involved the processing of problem solutions while simultaneously storing the last number of each problem. The results of this experiment were that the high-math-anxious group showed reduced working memory capacities compared to the low-math-anxious group, for both the listening span task and the computation span task. This indicates that math anxiety is not math specific, and that it will cause declines in working memory capacity even in non-mathematical tasks. Nevertheless, the difference in working memory span was more pronounced in the computation task compared to the listening task. The findings from this experiment illustrate the negative impact of anxiety on working memory measures.

The main explanation for the negative effects of anxiety on working memory is that high anxiety brings about self-centred interfering responses, such as saying "I am stupid" or "I'll fail!" (Baddeley, 1998). The constant mental repetition of such statements means that individuals become distracted from their task, and become impaired in their performance (Idzikowski & Baddeley, 1983). Ikeda, Iwanaga and Seiwa (1996) proposed that the mental repetition of statements through subvocalisation actually impacts more on tasks that require mental rehearsal (i.e., tap into the phonological loop) than tasks that require visuo-spatial processing (i.e., tap into the visuo-spatial sketchpad). This is because the negative self-statements essentially act as a secondary verbal task (much like articulatory suppression), which can interfere with performance on a primary verbal task, but not necessarily with a primary visual-spatial task.

A study by Markham and Darke (1991) investigated this premise more closely. They divided 36 young adults into a 'high anxiety' group and a 'low anxiety' group based on scores from an anxiety scale. Both groups of participants were then required to perform two verbal tasks and two spatial tasks in a random order. The verbal tasks consisted of a verbal reasoning task (verifying syllogisms) and a digit span task. The spatial tasks consisted of a spatial reasoning task (figure-matching) and a spatial span task (Corsi test). The results indicated that high anxiety did not cause significant impairments in the spatial reasoning task or in the digit span or spatial span tasks. However, high anxiety had a detrimental effect on the verbal reasoning task. The investigators concluded that anxiety acts as a secondary verbal task on verbal tasks that place heavy loads on working memory. The fact that anxiety did not affect the digit span task suggests that this task did not make heavy demands on working memory. Therefore, the results support the notion that the negative self-statements of highly anxious individuals act as a secondary verbal task, which impedes performance in certain verbal tasks, but not visuo-spatial tasks.

In another study by Lee (1999), young adults were divided into a high-anxiety group and a low-anxiety group based on their scores from the Test Anxiety Inventory (TAI). They were then asked to perform two types of verbal tasks (a rhyming judgement task and a verbal analogies task) and two types of visual-spatial tasks (symbol-rotation tasks and a paper-form-board task). The results were that high anxiety affected performance on the verbal-analogies task but not on the rhyming-judgement or visual-spatial tasks. One explanation for this is that anxiety acted as a secondary verbal task on the verbal-analogies task, because this task placed a heavy load on working memory. This confirms the results of Markham and Darke (1991), and implies that the negative self-statements of highly anxious individuals interfere with the functioning of the phonological loop, which affects performance on certain verbal tasks, but not visuo-spatial tasks.

Finally, a study by Elliman, Green, Rogers and Finch (1997) assessed the effect of anxiety on the articulatory loop, as well as on the central executive. A sample of 72 subjects were divided into a low, medium and high anxiety group, based on their scores on the Hospital Anxiety and Depression Scale (HADS). Participants were all asked to perform a sustained attention task, which tapped into the articulatory loop and the central executive components of working memory, as well as two psychomotor tasks. The sustained attention task involved being presented with a continuous stream of digits (1 to 9) and responding on a keyboard every time a sequence of three odd or three even numbers occurred consecutively. The results were that there were no differences in the number of correct hits in the sustained attention task across the three anxiety groups. There were also no group differences found for the two psychomotor tasks. However, in the sustained attention task, the response times of the high anxiety group were significantly longer than those of the other two groups. This suggests that subjects in the high anxiety group had slower processing speeds than subjects in the other two groups for the sustained attention task, even though in the psychomotor tasks the processing speeds were the same for all groups. These results imply that high levels of anxiety have a detrimental effect on the processing speed of individuals when performing a task that involves both the phonological loop and the central executive.

Since anxiety can be detrimental to working memory and particularly the phonological loop and the central executive, it is important to measure the anxiety states of individuals before they perform any working memory tasks. This was done for both experiments in this thesis (see Chapters 5 and 6).

Chapter 4: Mental Arithmetic and Visual Numerosity

The previous chapters have discussed aging, skill acquisition and transfer, working memory, and anxiety as separate topics. However, these topics may in fact be linked with one another in important ways. For example, it may be that factors such as working memory and anxiety affect the skill acquisition and transfer abilities of young and older adults. Therefore, the aim of the research conducted for this thesis (presented in Chapters 5 and 6) was to compare the acquisition and transfer of skills in young and older adults, and to determine whether age differences were related to age differences in working memory and anxiety. This investigation was performed in relation to two skills: mental arithmetic (a cognitive skill) and visual numerosity (a cognitive/perceptual skill). An extensive literature review of each skill is presented in this chapter.

Mental Arithmetic Skill

Acquisition Of Mental Arithmetic Skill

The acquisition of mental arithmetic skill has been researched extensively over the years. Several studies (e.g., Barrouillet & Fayol, 1998; Campbell & Graham, 1985; Kaye, Post, Hall, & Dineen, 1986) have found that in childhood, simple arithmetic problems are solved by the execution of a counting algorithm (e.g., 3 x 6 is solved by adding 6 + 6 + 6). However, with extensive practice throughout the school years, a transition occurs to retrieving the arithmetic facts from memory. Thus, by adulthood, most individuals solve single-digit operand problems by retrieving the solutions directly from long-term memory (Lefevre, Sadesky, &

Bisanz, 1996; Lemaire & Fayol, 1995; Rickard, Healy, & Bourne, 1994; Thevenot, Barrouillet, & Fayol, 2001). Campbell and Graham (1985) reported that adults can produce a correct solution to most multiplication facts in 1 second or less. Studies have found that the retrieval of such simple multiplication and addition facts is obligatory in most adults, in that they can be initiated even without the individual's intention (e.g., Lefevre & Kulak, 1994; Lemaire, Barrett, Fayol, & Abdi, 1994). Campbell (1997) also discovered that participants have similar reaction times and accuracy levels, and make similar errors when solving simple division and multiplication facts. Of particular interest was the fact that response times for related multiplication and division problems (e.g., 4 X 6 = 24, 24 ÷ 6 = 4) correlated highly with each other, and the errors made in related multiplication and division problems (e.g., 4 X 8 = 24, 24 ÷ 8 = 4) were similar in their characteristics. From these results, the researchers concluded that simple division and multiplication facts are probably retrieved from the same network.

Studies have also investigated how older adults retrieve simple arithmetic facts compared to younger adults. These studies have found that the rates of retrieval of mental arithmetic facts from long-term memory are equal in young and older adults, and sometimes even faster in older adults (e.g., Allen, Ashcraft, & Weber, 1992; Allen, Smith, Jerge, & Vires-Collins, 1997; Geary & Wiley, 1991; Geary, Frensch, & Wiley, 1993; Robinson, Arbuthnott, & Gibbons, 2002; Verhaeghen, Kliegl, & Mayr, 1997). One possible explanation for this is that older adults have stronger representations of arithmetic facts in their memory, due to constantly retrieving these facts throughout their lives. It is also possible that older adults were taught basic arithmetic facts in a better way compared to the teaching methods that are used today. On the other hand, older adults seem to experience perceptual problems when solving simple arithmetic, in that they are slower at encoding numbers and slower at expressing answers, compared to younger adults (e.g., Allen et al., 1997; Geary & Wiley, 1991; Geary et al., 1993). These decrements may be due to changes in the brain and in perception that occur with age (Lemme, 2002).

Since simple arithmetic problems are solved automatically by the time individuals reach adulthood (i.e., most people are 'skilled' at simple arithmetic by the time they are adults), it is problematic to use simple arithmetic to study skill acquisition in adults. Therefore, researchers have used alphabet arithmetic, and more complex arithmetic problems, to study skill acquisition in adults. For example, in the study by Logan and Klapp (1991) mentioned in Chapter 2, young adults were given equations of the form A + 2 = C or B + 3 = E and asked to verify whether these equations were true or false. To do this task initially, it was assumed that participants would count forward through the alphabet. However, with practice, this counting algorithm could be replaced by the retrieval of alphabet-arithmetic facts from memory (Logan, 1988). To determine whether this occurred, the researchers analysed the reaction time data of the participants. If participants were using a counting algorithm to perform the task, then a linear increase in reaction time would occur as the magnitude of the digit addend increased (since the addend determines how many counting steps are needed through the alphabet). In contrast, if performance was based on the retrieval of facts from memory, then the magnitude of the digit addend would be of no importance. Thus, the researchers predicted that automatic memory retrieval would create a slope of zero in the linear function of reaction time against the magnitude of the digit addend. Furthermore, if the reaction times of participants became faster with practice, this would also suggest that they were switching from algorithmic computation to memory retrieval to solve the problems. The results supported all these hypotheses, such that the performance of adults became automatic and memory-based with practice on this task.

In a similar experiment, Barrouillet and Fayol (1998) asked young adults to perform two tasks: a simple number arithmetic task and an alphabet arithmetic task. For the number arithmetic task, participants had to mentally transform a series of up to four numbers by adding or subtracting an operand of value 1, 2, 3, or 4 (e.g., the series 7, 17, 12 and the operand +2 gives 9, 19, 14). For the alphabet arithmetic task, participants were required to perform the same transformations, but with letters instead of numbers (e.g., the series F, D, T with the operand –3 gives C, A, Q). The results indicated that participants initially used algorithmic computation for the alphabet arithmetic task, possibly because the alphabet is rarely used for counting. However, with practice, the reaction times of participants became faster, suggesting a transition from algorithmic performance to retrieving solutions from memory (Logan, 1988). On the other hand, the number arithmetic task was performed consistently by automatically retrieving number facts from memory.

Studies have also used complex mental arithmetic to study skill acquisition. For example, the study by Greig and Speelman (1999) mentioned in Chapter 2 asked young adults to solve an algebraic equation of the form $(x^2 + 2y)$ by substituting values for x and y. The researchers predicted that participants would initially use algorithmic computation to solve the equations. However, with practice, participants would be able to learn and store the solutions of equations in their memory. Thus with practice, participants would start retrieving solutions from memory, resulting in faster performance (Logan, 1988). The results supported this hypothesis, with performance becoming significantly faster with practice, and following a power function.

The studies mentioned so far have all found that mental and alphabet arithmetic is learned by switching from general algorithmic strategies to memory-based strategies. However, these studies used young adults as their sample group. Only a small amount of research has also investigated the acquisition of alphabet arithmetic and complex mental arithmetic in the older adult age groups. For example, a study by Touron, Hoyer and Cerella (2001) mentioned in Chapter 2, asked young and older adults to either produce or verify solutions to alphabet arithmetic problems. The results from these tasks were that the data for both young and older adults could be described by power functions. This indicates that older adults learned the tasks in a similar way to younger adults, and became faster with practice. However, when the parameters of these functions were analysed, the results showed significant age differences favouring the younger adults. Specifically, the improvement span for young adults was greater than for older adults, and the learning rates and final reaction times of young adults were faster than those of older adults. However, the level of accuracy was approximately equal for both young and older adults.

In the study by Brigman and Cherry (2002) reported in Chapter 2, young and older adults were also required to perform an alphabet arithmetic task. In this task, participants were required to verify the accuracy of letter-number-letter strings (e.g., J[2]M, K[3]P). The results from this experiment were that both age groups showed a substantial decrease in reaction time with practice, suggesting that both age groups were learning the task. Both age groups also demonstrated high levels of accuracy. However, the older adults were consistently slower than younger adults in acquiring this alphabet arithmetic skill.

A study by Salthouse and Kersten (1993) investigated the way in which young and older adults learned a symbol arithmetic task rather than an alphabet arithmetic task. In symbol arithmetic, participants are required to substitute symbols for digits, and then perform mental addition or subtraction processes on these digits. The results of this task indicated that both age groups became faster with practice, and older adults made significantly less errors than young adults. However, older adults were considerably slower than younger adults overall when performing this task. The researchers attributed the age difference in performance to the slower processing speed of older adults. However, perceptual difficulties that arise from aging may also have contributed to the slower performance of older adults.

In terms of complex mental arithmetic, a study by Charness and Campbell (1988) reported in Chapter 2 investigated the acquisition of this skill in young, middle-aged and older adults. Participants were required to learn a mental squaring algorithm of the form $a^2 = (a + c)(a - c) + c^2$ in order to perform the task of squaring numbers. The results of the study indicated that older adults learned the skill at approximately the same rate as the younger adults. Older adults also made fewer errors than younger adults. However, the calculation speed of the older adults was about half that of the younger adults. Furthermore, it took about 3 minutes of practice per year of age difference for the performance of the older adults to equal that of younger adults (in their initial performance). Therefore, older adults were capable of learning this complex arithmetic task, but their performance on the task was slower than that of younger adults.

Finally, a study by Salthouse and Coon (1994) also investigated the acquisition of complex mental arithmetic skill in young and older adults. They asked participants to verify both sequential arithmetic problems (e.g., $5 + 3 - 1 - 3 + 4 - 1 = 6$) and hierarchical arithmetic problems (e.g., $[(5 + 3) - 1] - [3 + (4 - 1)] = 1$) over many trials. The hierarchical problems were deemed more difficult, since they could not be solved simply from left to right. The results of the study were that older adults became faster with practice and made approximately the same amount of errors as younger adults when solving these problems. However, older adults were significantly slower than younger adults when performing both types of problems, with a more substantial age difference for hierarchical problems than for sequential problems. This age group difference was attributed to a decline in speed of information processing.

Therefore, the results from the aging and mental arithmetic literature reveal that both young and older adults become faster with practice, suggesting that they learn the task by switching from slow effortful processing strategies (e.g., general algorithms) to fast and automatic processing strategies (e.g., memory retrieval). However, while the learning rate can be faster for young adults than for older adults (Touron et al., 2001), it can also be equivalent for both age groups (Charness & Campbell, 1988). The improvement span from the beginning to the end of training also seems to be greater for younger adults than for older adults (Touron et al., 2001). Other general findings are that older adults are as accurate, and sometimes more accurate, than younger adults when performing complex arithmetic tasks. However, older adults seem to be consistently slower at performing these tasks compared to younger adults. This has been attributed mainly to a decline in speed of information-processing with age.

Transfer Of Mental Arithmetic Skill

In terms of the transfer of arithmetic skill, Anderson's ACT* Theory (1982) proposes that the degree to which skills will transfer from one task to another will depend on the number of shared task components. More specifically, it will depend on the extent to which the same productions are involved in performing the two tasks. Therefore, the amount of transfer should be high when going from one set of arithmetic problems to another set of similar arithmetic problems that can be solved using the same productions. This theory has been supported by numerous studies (e.g., Frensch, 1991; Kieras & Bovair, 1986; Kramer, Strayer, & Buckley, 1990; McKendree & Anderson, 1987; Neves & Anderson, 1981; Novick, 1988; Singley & Anderson, 1985; Speelman & Kirsner, 1997). On the other hand, Logan's Instance Theory (1988, 1990) suggests that skills are specific to the context in which they were acquired, and cannot be easily transferred to a new context. Transfer to a new context is possible, but only if the new task involves specific events that have been encountered in the old task. That is, transfer will only occur if the new task involves the retrieval of the same arithmetic solutions (instances) as in the old task. If this is not the case, then performance will depend on the execution of an algorithm instead, and reaction times will revert to pre-practice levels. There have been numerous studies supporting this viewpoint as well (e.g., Green, 1997; Kirsner, 2001; Logan, 1998; Logan & Klapp, 1991; Masson, 1986; Speelman, Ward, & Churchill, 1998). However, while most of these studies have found that performance is disrupted initially at transfer, performance does not usually return to pre-practice levels. This suggests that some positive transfer does occur to tasks with new contexts, which is not entirely consistent with Logan's Instance Theory. Thus, several studies have found that transfer involves a combination of item-specific and item-general learning (e.g., Greig & Speelman, 1999; Knowlton & Squire, 1996).

Although Anderson's ACT* Theory (1982) is primarily concerned with general learning, it can account for specific learning as well. For example, during the training phase of a mental arithmetic task, individuals can develop item-general productions to solve the arithmetic problems. With practice, individuals can develop item-specific productions that are specific for certain arithmetic problems. However, in the transfer phase, the item-specific productions developed during training are no longer appropriate, which explains why performance is slower in the initial stages of the transfer phase compared to the end stages of the training phase. However, individuals can still use the item-general productions developed during training, which explains why their performance in the transfer phase does not return to pre-training levels.

The study mentioned earlier by Charness and Campbell (1988) investigated the transfer of a mental squaring algorithm in young, middle-aged and older adults. After an extensive training phase, participants underwent a transfer phase in which they performed the same task again, but were given a different set of numbers to square. The results showed partial transfer for each age group, with the young adults being significantly faster than the older adults. This supports Anderson's ACT* theory in which participants acquired both item-general and item-specific productions in the training phase, but were only able to use the item-general productions in the initial stages of the transfer phase.

The other study mentioned before by Touron et al. (2001), also investigated how well young and older adults could transfer alphabet arithmetic skills in a production and verification task. During the transfer phases of these tasks, participants were presented with alphabet arithmetic problems that were different to the ones presented during training. The results were that both age groups displayed partial transfer to the new set of problems, with young adults being significantly faster than older adults. This again supports Anderson's ACT* theory in which participants acquired both item-general and item-specific productions in the training phase, but were only able to use the item-general productions (initially) in the transfer phase. The fact that younger adults were not as impaired initially at transfer as older adults also suggests that younger adults were able to retain more general skills from the training phase compared to older adults.

From these two studies, it seems that older adults learn complex arithmetic skills through a combination of specific and general learning. Young adults also appear to use this combination of strategies when learning. However, the extent to which young and older adults rely on these different strategies cannot be confirmed until more research is conducted in this field.

Working Memory and Mental Arithmetic Skill

Working memory seems to play an important role in mental arithmetic skill (Adams & Hitch, 1997; Ashcraft, 1995; Hitch, 1978). Specifically, Baddeley and Logie (1999) propose that mental arithmetic uses the phonological loop to temporarily store partial solutions, and uses the central executive to retrieve algorithms that can calculate and estimate totals.

To investigate the function of the phonological loop in mental arithmetic, Logie, Gilhooly and Wynn (1994) asked subjects to perform a mental arithmetic task while concurrently performing a verbal task. Performing this concurrent verbal task caused more errors to be made in the arithmetic task compared to performing the arithmetic task alone, whether the numbers were presented verbally or visually. However, when participants were asked to perform a concurrent spatial task (such as tapping), their performance on the arithmetic task was not affected. This suggests that the phonological loop is strongly involved in mental arithmetic. A study by Blankenberger and Vorberg (1997) also supports this claim.

The study by Logie et al. (1994) also suggests the involvement of the central executive in mental arithmetic. The reason for this is that despite making more errors with a concurrent verbal task, participants were still able to guess approximately what the final total was, with guesses usually within 6% of the correct totals. This ability to make close approximations suggests that subjects were able to avoid the interfering effects of the concurrent verbal tasks. It is possible that subjects relied on learned strategies to make some of their approximations (e.g., calculating 20 + 20 + 20 instead of 17 + 19 + 24). In this case, subjects can guess that the final total is close to a certain value, without needing to calculate the actual sum or keep a running total. It is thought that the central executive may be responsible for selecting and applying such calculation strategies (Baddeley & Logie, 1999).

Baddeley (1966a) investigated the role of the central executive in mental arithmetic, by asking participants to perform a concurrent task that would disrupt the use of strategies. This concurrent task, called oral random generation, required subjects to randomly generate as many sequences of alphabet letters as possible. This task places demands on the central executive, because subjects need to actively keep track of what letters they have already generated, while avoiding the use of well-learned or stereotyped letter sequences such as ABC or MTV. Furthermore, this task involves the continuous production of verbal information, which interferes with the functioning of the phonological loop. Doing this task concurrently with an arithmetic task resulted in a high rate of errors (approximately 40% error rate). In fact, some participants were completely unable to do the two tasks simultaneously. In addition, subjects made worse approximations of the real totals with the random generation task than they did with the articulatory suppression or irrelevant speech tasks (Baddeley & Logie, 1999). This suggests that the central executive plays a crucial role in performing mental arithmetic. Numerous other studies have found evidence for the involvement of both the phonological loop and central executive in mental arithmetic (e.g., De Rammelaere, Stuyven, & Vandierendonck, 1999; Furst & Hitch, 2000; Hecht, 2002).

Some researchers (e.g., Frick, 1988; Seron, Pesenti, Noel, Deloche, & Cornet, 1992) have also proposed that numbers are represented visually in the visuo-spatial sketchpad (VSSP) of working memory, and that the VSSP is therefore involved in mental arithmetic. However, the limited amount of research in this area suggests that the VSSP plays only a small role in mental arithmetic. For example, Noel, Desert, Aubrun and Seron (2001) asked participants to perform a complex mental addition task when the numbers presented were phonologically similar, and when the numbers presented were visually similar. The researchers found that the speed and accuracy of participants in this task was significantly impaired when the numbers were phonologically similar, but not when they were visually similar. The researchers concluded that the phonological loop plays an important role in mental addition, whereas the VSSP does not. Another study by Trbovich and Lefevre (2003) investigated the phonological loop and VSSP in mental arithmetic by using dual task methodology. In this study, participants were asked to perform a complex mental arithmetic task either alone, or concurrently with a verbal memory task (remembering a list of nonwords) or a visual memory task (remembering random patterns of asterisks). The results indicated that performance in the concurrent verbal condition was more impaired than in the concurrent visual condition. This suggests that the VSSP may have some involvement in complex mental arithmetic, but not to the same extent as the phonological loop. Wilson and Swanson (2001) found similar results. In their study, participants with and without mathematics disabilities were required to complete four working-memory tasks to assess verbal and visuo-spatial processing. A regression analysis on the data revealed that verbal working memory accounted for a larger percentage of the variation in mathematics ability than visuo-spatial working memory. Thus, the research suggests that the phonological loop is substantially more involved in performing mental arithmetic than the VSSP. The phonological loop is thought to temporarily store partial solutions and to keep track of running totals using subvocal rehearsal. At the same time, the central executive allows the individual to select calculation algorithms or strategies to use with arithmetic problems (Baddeley & Logie, 1999).

Since the phonological loop and central executive are both involved in performing mental arithmetic, it is important to determine whether changes occur in these working memory components with age. This is especially necessary if researchers want to compare the performance of young and older adults in mental arithmetic tasks. The majority of studies (reported in Chapter 3) have found that the phonological loop actually remains intact with age. There is evidence that older adults are just as capable as younger adults at ignoring irrelevant speech with verbal tasks (e.g., Rouleau & Belleville, 1996) Also, older adults do not become more severely impaired than younger adults when performing concurrent articulatory suppression with verbal tasks (Phillips & Hamilton, 2001). Moreover, studies comparing the phonological loop and the VSSP in young and older adults have found that the phonological loop is more resistant to aging than the VSSP (e.g., Dolman, Roy, Dimeck & Hall, 2000; Jenkins, Myerson, Joerding & Hale, 2000; Tubi & Calev, 1989). The finding that older adults sometimes perform more poorly than younger adults in digit span tasks can be attributed to the slower articulation rates of older adults rather than problems with their phonological loop (Phillips & Hamilton, 2001).

On the other hand, the empirical research suggests that the central executive deteriorates with age. There is evidence that older adults perform more poorly than younger adults in 'keeping track' tasks (e.g., Dobbs & Rule, 1989), random generation tasks and the Tower of London task (e.g., Phillips, Gilhooly, Logie, Della Sala, & Wynn, 2001; Van der Linden, Bregart, & Beerten, 1994). There is also neuropsychological evidence that the frontal lobes deteriorate with age (Coffey, Wilkinson, Parashos, Soady, Sullivan, Patterson, Figiel, Webb, Spritzer, & Djang, 1992; Coleman & Flood, 1987; Raz, Gunning, Head, Dupuis, & Acker, 1998) and that the performance of older adults is impaired in neuropsychological tests when compared to younger adults (Rabbit, 1997; Rogers & Fisk, 1991; Shimamura & Jurica, 1994). Furthermore, studies using correlational methodology (e.g., Fisk & Warr, 1996) or manipulating the storage and processing components of tasks (e.g., Craik, Morris, & Gick, 1990; Morris, Craik, & Gick, 1990), or using dual task methodology (e.g., Hamilton, Coates, & Heffernan, 2003) have all found that the central executive becomes impaired with age. One general explanation for these results is that there is a decrease in the speed of information processing that occurs with age. This slowing down of information processing has a negative impact on the efficiency of the central executive, and on the whole of working memory as a consequence. Based on these findings, older adults may experience difficulties when performing complex mental arithmetic tasks.

Several studies have investigated this particular issue. For example, a study mentioned earlier by Salthouse and Coon (1994) asked young and older adults to perform two working memory tasks, and to verify mental arithmetic problems of differing complexity. Complexity was manipulated by presenting arithmetic problems either in a sequence (e.g., 5 + 3 – 1 = 7) or in a hierarchy by using brackets and parentheses (e.g., [5 + (3 – 1)] = 7). The researchers proposed that sequential problems are easier to solve, because participants only need to remember the product of a previous operation in order to solve the current operation. In contrast, the hierarchical problems are more difficult to solve, because equations in brackets need to be solved first, and the products of these equations need to be retained in order to solve the overall equation. Thus, there are more processing steps involved in solving hierarchical problems, and an increased load on working memory. The results of the study were that older adults were significantly slower than younger adults when performing both types of arithmetic tasks. However, the age difference was more substantial for hierarchical problems than for sequential problems. Furthermore, the age difference for arithmetic problems was greatly reduced after statistical control of information-processing speed data, but minimally reduced after statistical control of working memory data. This implies that age differences in this task were due to changes in information-processing speed with age, rather than changes in working memory. Similarly, Lincourt, Rybash and Hoyer (1998) found that age differences in the performance of an alphabet arithmetic task could not be explained by age differences in working memory.

On the other hand, Verhaeghen et al. (1997) investigated the ability of young and older adults to produce answers to sequential and hierarchical (or coordinative) problems. However, unlike Salthouse and Coon (1994), they did not find age differences in both types of arithmetic tasks, but only in the hierarchical task. That is, older adults were slower and less accurate than younger adults in solving the hierarchical problems only. The fact that age equivalence was achieved in sequential problems suggests that older adults were as fast as younger adults in performing simple mental arithmetic. However, the poorer performance of older adults in hierarchical problems may be due to deficits in their working memory capacity, since these problems relied on working memory to process and store intermediate calculations. Alternatively, older adults may experience more difficulty with hierarchical problems because the brackets prevent the problems from being solved from left to right, and force the individuals to solve the problems from the innermost brackets first. This scheduling of operations involves the use of the central executive, which is thought to deteriorate with age (Rabbit, 1997; Rogers & Fisk, 1991; Shimamura & Jurica, 1994).

Oberauer, Demmrich, Mayr and Kliegl (2001) investigated the role of the central executive further by asking young and older adults to solve sequential arithmetic problems under three different conditions. In the control condition, arithmetic problems were solved by substituting variables in the equations with numbers on a screen. In the memory load condition, arithmetic problems were solved in the same way, but participants had to perform a verbal task (remembering a set of three digits) at the same time. In the access condition, arithmetic problems were solved by substituting variables in the equations with letters on a screen, and substituting the letters on the screen with numbers from the verbal task memory set. Thus, in this condition, participants had to retrieve information from the memory set in order to solve the arithmetic task. Furthermore, the access condition involved two processing steps (substituting variables with letters, and letters with numbers) whereas the memory load condition only involved one processing step (substituting variables with numbers). It was predicted that the extra processing component in the access condition would place demands on the central executive, which is thought to deteriorate with age. The results were that older adults performed more poorly in speed and accuracy compared to younger adults in all three conditions. However, the age difference in performance was greatest in the access condition, followed by the memory load condition, followed by the control condition. The fact that older adults experienced the most difficulty with the access condition suggests that they had an impaired ability to access information from working memory, or they had an impaired ability to coordinate multiple processing tasks (involving the central executive). To test these theories, the researchers conducted a second experiment, in which the memory load and access conditions were equated in terms of their executive demands. That is, the task in the access condition was changed so that it no longer needed two substitution steps to solve the problems. When this was done, the performance of young and older adults in the access condition was affected to the same degree. This implies that selective access to working memory does not deteriorate with age, and that the results from the first experiment can be explained by a decline in executive functioning with age. A later study by Oberauer, Wendland and Kliegl (2003) confirmed these findings.

Campbell and Charness (1990) also investigated the role of working memory in complex calculation with young, middle-aged and older adults. This study was similar to that of Charness and Campbell (1988) in that participants had to learn an algorithm for squaring 2-digit numbers over six sessions. However, this study focussed more on the role of working memory during the acquisition of the squaring task. The algorithm used by participants placed demands on their working memory control processes (e.g., selecting the next subtask, retrieving results from a previous operation to perform the current operation, etc.) as well as long-term retrieval processes (e.g., retrieval of rules and arithmetic facts from long-term memory).

Therefore, the researchers were able to classify squaring errors as either working-memory failures (e.g., omitting a subgoal, retrieving the wrong results from previous operations, making incorrect substitutions or deletions) or as calculation errors (e.g., retrieving incorrect arithmetic solutions from long-term memory). The results were that all age groups improved their performance in this task with practice. However, the older age groups were consistently slower than the younger age group across the six sessions. Moreover, the older age groups made significantly more working memory errors and calculation errors than the younger age groups. These age-related differences in calculation errors were completely eliminated with practice. However, the age-related differences in working memory did not disappear with practice. The older age groups also made a greater proportion of working memory errors compared to calculation errors. These results suggest that working memory plays an important role in mental arithmetic, and becomes less efficient with age.

Finally, the study mentioned earlier by Brigman and Cherry (2002) investigated the role of working memory and processing speed in alphabet arithmetic tasks, in young and older adults. Processing speed was measured with a digit-symbol substitution task, while working memory was measured with a size judgement span task, a computation span task, and a listening span task. The results were that both age groups became faster at alphabet arithmetic with practice. Although the older age group achieved approximately the same accuracy level as the younger age group in this task, they were consistently slower than the younger age group throughout the practice sessions. Furthermore, the researchers found that processing speed and working memory were both significantly correlated with performance, but only at the end of training. This is at odds with Woltz (1988) who suggested that working memory is important in the initial stages of skill acquisition, when performance relies on the use of an algorithm rather than memory. Brigman and Cherry explained their results by suggesting that their task did not place enough demands on working memory initially. However, the correlation of working memory with final performance implies that working memory can play an important role in the retrieval of instances from long-term memory.

Therefore, the empirical research suggests that older adults can perform as well as younger adults in mental arithmetic tasks that involve simple arithmetic. However, older adults can experience mild impairments in speed and/or accuracy when performing sequential problems, and substantial impairments when performing hierarchical or complex problems. Their difficulty with complex arithmetic may be due to a decline in working memory efficiency with age, and particularly deterioration in executive functioning with age. The finding that working memory can be correlated with performance at the end of training suggests that it can also play an important role in the retrieval of instances from long-term memory.

Anxiety and Mental Arithmetic Skill

Many studies have found that anxiety impairs performance in cognitive tasks such as analogical reasoning (Tohill & Holyoak, 2000), verbal reasoning (Markham & Darke, 1991), geometrical analogies (Leon, 1989) and grammatical reasoning (MacLeod & Donnellan, 1993). Individuals that are highly anxious usually perform slower and less accurately on these tasks compared to individuals that are mildly anxious (Leon & Revelle, 1985).

Similarly, studies have found that anxiety has a detrimental effect on mental arithmetic. For example, Ashcraft and Faust (1994) measured maths anxiety and divided participants into low, medium and high anxiety groups. Participants were then required to perform a range of mental arithmetic problems. Overall, the results showed that the low anxiety group performed the problems faster and with the least amount of errors, the medium anxiety group performed consistently slower than the other two groups, and the high anxiety group made the most errors out of the three groups. Hopko, McNeil, Lejuez, Ashcraft, Eifert and Riel (2003) also found that high math anxious individuals exhibited higher error rates than low math anxious individuals in mental arithmetic. This difference in anxiety groups was particularly evident when the mental arithmetic task increased in complexity, and utilised more working memory resources. Kellogg, Hopko and Ashcraft (1999) found these same results in their study. Furthermore, if mental arithmetic is performed on a computer, then computer anxiety can also negatively affect performance (Mahar, Henderson, & Deane, 1997).

Several researchers have found that anxiety impairs performance by interfering with working memory functioning. For example, Hopko, Ashcraft and Gute (1998) found that participants with high and medium math anxiety took significantly longer to read paragraphs with distractors, and made more comprehension errors, compared to participants with low math anxiety. The researchers proposed that math-anxious individuals find it more difficult to inhibit or suppress their attention to distractors than low math-anxious individuals. This deficient inhibition mechanism means that working memory resources are being allocated to distractor information as well as target information. As a consequence, there are less working memory resources available for problem solving, which results in poorer performance in mental arithmetic.

Ashcraft and Kirk (2001) also investigated the relationship between anxiety and working memory, by asking participants to complete a mathematics anxiety scale and two measures of working memory (a listening span and a computation span). The results indicated that participants with high math anxiety had smaller working memory spans, especially when measured with the computation span task. Participants were then asked to perform a mental addition task, with problems ranging from one-digit addends to two-digit addends. They were also required to perform a concurrent memory load task, where they had to remember two or six random letters in working memory. This dual-task procedure allowed the investigators to manipulate demands placed on working memory. The results were that high anxiety individuals were more impaired than low anxiety individuals when performing the two tasks concurrently, especially when the difficulty of both tasks was raised (thereby placing heavy demands on working memory). The researchers concluded that individuals with high anxiety have less efficient working memory functioning, which in turn causes poorer performance in arithmetic tasks (especially when another verbal task is performed concurrently).

Numerous other studies have found that anxiety has a negative impact on working memory (e.g., Idzikowski & Baddeley, 1983a; Idzikowski & Baddeley, 1987; Moldawsky & Moldawsky, 1952; Mueller, 1980). It has been proposed that high anxiety brings about self-centred interfering responses, such as saying "I am stupid" (Baddeley, 1998). The constant mental repetition of such statements means that individuals become distracted from their task, and become impaired in their performance (Idzikowski & Baddeley, 1983b). Ikeda, Iwanaga and Seiwa (1996) proposed that the negative self-statements essentially act as a secondary verbal task (much like articulatory suppression), which can interfere with performance on a primary verbal task. This theory has been supported by several studies (e.g., Lee, 1999; Markham & Darke, 1991). Since mental arithmetic involves the phonological loop and can be considered as a verbal task, performance on this task is likely to be affected by anxiety.

In summary, the anxiety research suggests that high levels of anxiety can have a negative impact on the performance of individuals (in terms of slower reaction times and lower levels of accuracy) when learning mental arithmetic. Furthermore, high levels of state or trait anxiety can interfere with working memory functioning, which in turn interferes with skill acquisition.

Mental Arithmetic: Conclusions

In conclusion, both young and older adults seem capable of acquiring new mental arithmetic skills. Both age groups become faster with practice, and are likely to switch from slow effortful processing strategies (e.g., general algorithms) to fast and automatic processing strategies (e.g., memory retrieval) by the end of practice. Younger adults are usually faster at performing the task and have faster learning rates and greater improvement spans compared to older adults. However, older adults can be as accurate, and sometimes more accurate, than younger adults.

When participants are required to transfer skill from one arithmetic task to another, where the second task is identical to the first except for the stimuli used (i.e., different arithmetic problems are used), it seems that both young and older adults can transfer some of their skill from one task to another. This implies that both age groups are learning general arithmetic skills during training. However, the fact that performance is severely impaired for both age groups at transfer suggests that they have also learned specific arithmetic skills that cannot be easily transferred to a new task.

It is conceivable that working memory plays an important role in the performance of young and older adults when learning new arithmetic skills. For example, several studies have found that older adults can experience substantial impairments when performing hierarchical or complex arithmetic problems. Their difficulty with complex arithmetic may be due to a decline in working memory efficiency with age, and particularly deterioration in executive functioning with age. The finding that working memory can be correlated with performance at the end of training also suggests that it can also play an important role in the retrieval of instances from long-term memory.

High levels of state or trait anxiety also seem to have a negative impact on the performance of individuals (in terms of slower reaction times and lower levels of accuracy) when learning mental arithmetic. Furthermore, high levels of state or trait anxiety can interfere with working memory functioning (especially the functioning of the phonological loop), which in turn impairs skill acquisition. Therefore, both working memory and anxiety are factors that can influence the performance of subjects during the acquisition and transfer of mental arithmetic skill.

Visual Numerosity Skill

Acquisition And Transfer Of Visual Numerosity Skill

Visual numerosity is a task in which participants are presented with a number of items on a visual display screen, and are asked to report the number of items present. Visual numerosity can be described as a perceptual skill because it relies heavily on visual perception in order to learn and perform it. Like most other perceptual skills, the acquisition of visual numerosity involves a change from slow, effortful performance to fast and automatic performance. As such, the process of learning this skill can be described by Anderson's ACT* Theory (Anderson, 1982; 1983; 1987) or Logan's Instance Theory (Logan, 1988).

Several studies have found that adults can report the numerosity of up to 4 items quickly, accurately and without effortful processing (Atkinson, Campbell, & Francis, 1976; Atkinson, Francis, & Campbell, 1976; Folk, Egeth, & Kwak, 1988; Trick & Pylyshyn, 1993). This enumeration process has been referred to as 'subitising' (Kaufman, Lord, Reese, & Volkmann, 1949). However, the performance of adults is slower, less accurate and effortful when they must report the numerosity of 5 or more items. In this case, adults are using a process called 'counting' (Trick & Pylyshyn, 1993). The distinction between the subitising process and counting process has been supported by several neuropsychological studies (eg., Dehaene & Cohen, 1994; Sathian, Simon, Peterson, Patel, Hoffman, & Grafton, 1999; Watson & Humphreys, 1999).

Since adults are already 'skilled' at reporting the numerosity of 1 to 4 items, studies on skill acquisition use visual displays of 5 or more items. Therefore, when these visual displays are presented repeatedly over many trials, adults must initially employ a counting algorithm to determine the numerosity of the items. However, with practice, this counting algorithm can become more efficient (Anderson, 1982; 1983; 1987) or can be replaced by memory retrieval (Logan, 1988). This results in a speed-up in reaction time with practice, with performance resembling a power or exponential function (Lane, 1987).

According to Anderson's ACT* theory (1982, 1983, 1987), the counting algorithm starts off as a series of task-general productions (e.g., a production for marking items, for mapping numbers onto items, for finding the final numerosity of items, and so on). With practice, multiple productions are compiled into single productions that are more efficient, specific, and fast. These productions are no longer accessible for verbal reporting. The result is that performance on the task speeds up and places less demands on working memory. In contrast, Logan's instance theory (1988) proposes that participants initially use a counting algorithm to determine the numerosity of visual displays. However, as the visual display patterns and their associated numerosities are repeated over many trials, participants start to store these as instances in memory. The presentation of a familiar pattern then acts as a cue for the retrieval of its corresponding numerosity from memory. As more patterns and corresponding numerosity levels are stored in memory, it becomes more likely that the numerosity of a pattern is determined by fast memory retrieval rather than algorithmic counting. This explains why performance becomes faster and automatic by the end of practice (Palmeri, 1997; 1999).

In terms of transfer, the ACT* theory predicts that changing the visual displays (by changing the characteristics of the items within them) will not affect performance, since the basic underlying numerosity task remains the same. However, instance theory predicts that changing items will have a detrimental effect on performance, because the instances stored during training can no longer be used at transfer. To test these predictions, Lassaline and Logan (1993) asked participants to perform a visual numerosity task using displays of 6 to 11 items. After an extensive training phase, participants were presented with new visual displays that still contained 6 to 11 items. However, the items in the transfer phase differed from those in the training phase, either in identity (different letters of the alphabet), in colour (different colour configurations) or in orientation. The researchers found that changing the identity or colour of items did not significantly affect performance at transfer. However, changing the pattern orientations at transfer did have a significant impact on performance. This suggests that participants are learning item-specific information about the patterns during training, because the learning that occurred during training did not transfer to patterns with novel configurations. The fact that performance was impaired when patterns changed in orientation, suggests that each pattern was stored as a whole in memory. Therefore, Logan's instance theory was supported in this case.

Similarly, the study by Green (1997) mentioned in Chapter 2 used a visual numerosity task to investigate the instance theory's transfer predictions. During a training phase, participants were presented with repeated patterns of 8 to 10 items on a computer screen, and asked to count the items on the screen. During the transfer phase, participants were presented with patterns that differed from the original patterns, either in terms of the overall pattern configuration, or in terms of item identities (e.g., using 'bottles' for the 8-item pattern; 'bunnies' for the 9-item pattern, and so on). Since the patterns were different in the transfer conditions, participants could not rely on their memories of familiar patterns to determine the numerosity of the new patterns. Thus, instance theory predicted that the performance of subjects would be impaired in the transfer conditions. This prediction was supported. However, the fact that performance did not return to pretraining levels suggests that some positive transfer did occur, and that participants were also engaging in general learning during training (in line with Anderson's ACT* theory).

The importance of pattern configuration or item locations in specific learning was also illustrated by Logan (1998) using a category search task. In this study (also mentioned in Chapter 2) participants were required to search through one- or two-word displays for members of a target category (e.g., metals). During the training phase, target items appeared consistently in the same locations, while during the transfer phase, the locations of targets were changed. Logan predicted that performance would be disrupted in the transfer phase, because the visual displays were different to the training phase. However, changing the locations of targets did not have a detrimental effect on the performance of participants. Logan thought that maybe too many words were associated with too few locations (only two locations). Indeed, when words were presented in 16 different locations instead of two, performance was impaired at transfer as predicted by the instance theory. This provides support that individuals do encode the locations of targets when learning a visual task.

The studies mentioned so far have looked at the acquisition of visual numerosity in young adults. However, relatively little research has been conducted on the acquisition of visual numerosity in older adults. In one study by Sliwinski (1997), young and older adults were presented with visual displays of targets (O's) amongst a background of distractors (X's) and asked to count the number of targets in each trial. The number of target O's varied from 1 to 9. Sliwinski found that older adults performed the task more slowly than younger adults. However, when the slopes of the power functions were analysed, the rate of counting in younger adults was found to be significantly faster than that of older adults for counting 1 to 4 items (i.e., subitising), but not for counting more than 5 items. This suggests that aging slows down the rate of subitising, but not the rate of counting, in visual numerosity tasks. On the other hand, the accuracy level of young adults was significantly higher than that of older adults when counting 5 or more items, but equal when counting 1 to 4 items.

Basak and Verhaeghen (2003) suggested that the age difference in speed of subitising might be due to a statistical artefact. They proposed that the number of items that can be subitised (i.e., the subitising range) may be different across different individuals and different age groups. Therefore, if the subitising range for older adults is actually smaller than that of younger adults, then older adults are probably using the slow serial counting process for numerosities that are assumed to employ automatic processing. This would result in the subitising slope of older adults being overestimated. The researchers tested this theory by calculating the subitising speed of each individual from their subitising slopes. They found that indeed, older adults had smaller subitising spans (2.07) compared to younger adults (2.83). When these individual differences in subitising range were controlled for, no significant age differences were found in either the rate of subitising or counting. Furthermore, older adults were significantly more accurate than younger adults throughout the experiment.

Finally, one study did compare the transfer of visual numerosity skill in young and older adults. A study mentioned in Chapter 2 by Jenkins and Hoyer (2000) asked young and older adults to determine the number of items in visual displays of 6 to 11 targets. Performance in the training phase indicated that both young and older adults achieved automaticity in this task, but older adults were generally slower to do so compared to younger adults. The power function analyses also showed that the learning rates for older adults were slower than for younger adults. That is, older adults took longer to change from algorithmic performance to automatic performance compared to younger adults. In the transfer phase, the targets in the visual displays were changed in identity and/or location. This change of targets (stimuli) in the transfer phase meant that participants could not rely on past instances from the training phase to perform the task, but had to rely instead on the execution of algorithms or procedural learning. The results indicated that performance was greatly impaired for both age groups in the transfer phase when either the identity or the location of targets was changed. Performance at transfer was most impaired when both the identity and location of targets was changed. This suggests that young and older adults did not depend significantly on procedural learning to learn the visual displays. Instead, they learned the displays mostly by associating the numerosities with the target identities and/or locations, and storing these associations as instances in memory. The lack of age differences in the transfer phase implies that both age groups relied on item-specific learning to the same extent. However, Jenkins and Hoyer did not report on whether the reaction times at transfer actually returned to pre-training levels, and as such, it is unclear whether a certain amount of general learning also occurred for both age groups.

Therefore, the results from the aging and visual numerosity literature suggest that both young and older adults become faster at counting more than 5 items with practice, implying that they actively learn the task. However, older adults are usually slower at performing this task and can have different accuracy levels compared to younger adults. The research on learning rates also suggests that while older adults can count at the same rate as younger adults, they take longer to switch from algorithmic performance to automatic performance compared to younger adults (i.e., older adults have slower learning rates). On the other hand, older adults seem to learn the task of visual numerosity in the same way as younger adults, by eventually relying on the storing of instances in memory.

Working Memory and Visual Numerosity Skill

In order to perform the counting process in the visual numerosity task, the individual must have knowledge of the counting sequence, as well as temporary storage of the running total (Baddeley & Logie, 1999). It seems that the phonological loop is responsible for keeping track of this running total (Hitch, 1978; Logie & Baddeley, 1987).

In one study by Nairne and Healy (1983), subjects were asked to count backwards, out loud. Although this task was very simple and subjects made few errors, most of the errors that were made were the omission of numbers with repeated digits (e.g., 88, 66). Nairne and Healy (1983) proposed that numbers with repeated digits were causing phonological confusion in subjects, suggesting the involvement of the phonological loop, and especially the phonological store, in counting.

A more involved study, by Logie and Baddeley (1987), investigated the counting ability of subjects in two different tasks. The first task involved the counting of items in stimulus arrays. The second task involved the counting of event sequences (i.e., counting how many times a square appeared at irregular intervals in the centre of a computer screen). For each of these tasks, subjects were required to perform an articulatory suppression task at the same time. The results were that subjects made more errors in both tasks when they performed the articulatory suppression task concurrently. Moreover, the number of errors increased as the number of items or events presented in the tasks increased. To investigate whether this increase in errors was simply due to the disruption from a second task, Logie and Baddeley (1987) repeated the experiment using a concurrent hand-tapping task rather than a concurrent articulatory suppression task. The result from this experiment was that concurrent hand-tapping did not cause more errors in the two counting tasks.

The fact that the concurrent verbal task interfered with counting while the concurrent spatial task did not, suggests that the phonological loop is heavily involved in the counting process and is almost certainly responsible for keeping a running total. Further support for this notion comes from Buchner, Steffens, Irmen and Wender (1998), who found that irrelevant background speech caused detrimental effects on the counting of event sequences.

The central executive may also be involved in the counting process. In a study by Tuholski, Engle and Baylis (2001) an operation span task was administered to 60 individuals to measure their working memory (WM) spans. The 15 participants who scored in the upper quartile were considered the 'high WM' group while the 15 who scored in the bottom quartile were considered the 'low WM' group. Participants were then presented with a task in which they had to count up to 12 vertical yellow bars that were presented randomly on a computer screen. The results were that participants with high WM spans had higher subitising spans (3.35 objects) compared to participants with low WM spans (3.25 objects). This difference was not statistically significant, suggesting that the automatic, memory-based processing of the two groups was approximately the same. However, the two groups did differ significantly in the counting time required for 4 to 12 objects, with high WM subjects being consistently faster than low WM subjects. This suggests that individuals with high working memory spans were better at controlled attention and processing compared to individuals with low working memory spans. According to Engle, Kane and Tuholski, (1999), counting 4 to 12 objects requires controlled attention, because the individual must keep track of what they have already counted. Therefore, it seems that individuals with high working memory spans are better able to keep tags on the objects that they have already counted.

In a second experiment by Tuholski et al. (2001), the counting task was manipulated so that individuals were forced to use controlled processing even for 1 to 3 objects. In one condition (the 'conjunctive condition'), participants were presented with distractor objects that shared physical features with target objects (e.g., orientation and colour), while in the other condition (the 'disjunctive condition') participants were presented with distractor objects that did not share physical features with the target objects. Since the conjunctive condition used distractors that were similar to targets, subjects needed to control their attention and processing when counting, even when there were only 1 to 3 objects. However, in the disjunctive condition, distractors were different from targets so that subjects could rely on their automatic processing for 1 to 3 objects. The results were that both the high and low WM span participants were impaired at counting 1 to 3 objects in the conjunctive condition, but not in the disjunctive condition. Moreover, the impairment was much greater for the low WM span group than for the high WM span group. This suggests that high WM subjects were better at controlling their attention and processing in the conjunctive condition compared to low WM subjects. However, in the disjunctive condition there was no difference between the groups, since both used automatic processing. These studies illustrate the importance of controlled attention and processing capability in counting tasks. Since the central executive presumably regulates attention and processing functions, it certainly plays a large role in counting.

However, there may also be a role for the visuo-spatial sketch-pad (VSSP) in visual numerosity tasks. For example, the phonological loop and the central executive seem to be important in the initial stages of the counting process, because individuals typically use algorithms and procedural knowledge to perform the task.

However, with practice, participants may start to process and encode display patterns and their corresponding numerosities, and store these as instances in long-term memory. Indeed, several studies have found that participants eventually perform a numerosity task by retrieving solutions from memory rather than using a counting algorithm (e.g., Green, 1997; Lassaline & Logan, 1993; Logan, 1998). A small number of studies have investigated how individuals process and encode visual patterns.

Chun and Jiang (1998) propose that the global properties of a visual pattern actually aid in the encoding of that image, by directing attention towards important aspects of the image. This process is referred to as 'contextual cueing', and is thought to be a form of implicit learning. Furthermore, the researchers propose that the contextual information is stored implicitly in long-term memory as 'instances' (Logan, 1988). Thus, individuals use contextual cueing to achieve memory-based automaticity in performance. In order to test this theory, the researchers presented participants with visual displays containing targets among distractor items. Half of the visual displays were repeated across trials, with targets appearing in consistent locations, while the other half of the displays had novel configurations. It was hypothesised that with practice, sensitivity to the global properties of displays would result in faster target search performance in repeated visual displays compared to novel visual displays. The results supported this hypothesis. Moreover, participants were never told about the repetition of displays nor were they told to encode the displays in any way. Therefore, the learning that occurred in this task was incidental and implicit. The results suggest that individuals make associations between spatial configurations (global context) and target locations, which aids in their performance.

Furthermore, the visuo-spatial sketchpad is likely to be the system responsible for making these associations.

The ability of individuals to encode item locations in visual displays has also been investigated in other studies. For example, Postma and DeHaan (1996) proposed that the encoding process involves two separate processes: 'positional encoding' whereby participants encode the general locations of objects, and 'object-to-position assignment' whereby participants remember the specific locations for specific objects. The researchers found evidence for these two distinct processes, because participants were less accurate in relocating specific objects within displays compared to reconstructing the positions of identical objects. Performing a concurrent articulatory suppression task (counting backwards) also had a different effect on the two processes, in that it caused great impairments in relocating specific objects, but minimal impairments in reconstructing positions for identical objects. Thus, there is evidence for two separate processes occurring during visual encoding, and it is probable that the visuo-spatial sketchpad is involved in regulating these processes during visual numerosity tasks.

Lagasse (1993) also investigated whether the global form and spatial frequency of visual patterns affected their later recognition. Participants were asked to rate patterns of different spatial frequencies as having either 'good' global form or 'poor' global form. Participants were also required to perform a number of attentional tasks, in which they had to decide whether two patterns were the same or different. Lagasse found that individuals judged patterns with many elements as having better global form than patterns with few elements. Furthermore, participants were faster at performing the attentional tasks when the patterns in the tasks had 'good' global form compared to 'poor' global form. These results suggest that visual displays with good global form and low spatial frequencies are more easily processed and encoded by the visuo-spatial sketchpad than visual displays that have poor global form and high spatial frequencies. This processing and encoding of particular visual displays allows individuals to recognise the patterns if they are presented later, and thus helps with their performance in visual attention tasks.

Therefore, the research on working memory suggests that the phonological loop is involved in the initial stages of visual numerosity tasks, because the individual must have knowledge of the counting sequence, and must keep track of the running total. Similarly, the central executive is involved in the initial stages of visual numerosity tasks, because it regulates the individual's attention and processing functions. However, the visuo-spatial sketchpad becomes involved in the later stages of visual numerosity tasks, as visual patterns are repeated across trials. This is because individuals start to process and encode the global form of visual patterns, and may eventually store these visual patterns with their associated numerosities as 'instances' in long-term memory. This process of contextual cueing or positional encoding by the VSSP probably helps participants to eventually perform the numerosity task by retrieving solutions from memory rather than using a counting algorithm.

Since all three components of working memory are involved in performing visual numerosity tasks, it is important to determine whether changes occur in these working memory components with age. From the literature search presented earlier in this chapter, it seems that the phonological loop remains intact with age (Dolman et al., 2000; Jenkins et al., 2000; Phillips & Hamilton, 2001; Rouleau & Belleville, 1996; Tubi & Calev, 1989) whereas the central executive seems to deteriorate with age (Dobbs & Rule, 1989; Kramer & Atchley, 2000; Phillips et al., 2001; Van der

Linden et al., 1994). As for the visuo-spatial sketchpad, it also seems to become impaired with age. For example, older adults perform more poorly than younger adults in the visuo-spatial memory game of Concentration (Chagnon & McKelvie, 1992), older adults are impaired in imagery tasks compared to younger adults (Cerella, Poon, & Fozard, 1981; Dror & Kosslyn, 1994) and older adults are less efficient at using imagery compared to younger adults (Dirkx & Craik, 1992). Studies have also found that older adults have more difficulty in visual search tasks compared to younger adults (Davis, Fujawa, & Shikano, 2002; Fisk & Rogers, 1991; Fisk, Rogers, & Giambra, 1990; Rogers, 1992; Rogers, Fisk, & Hertzog, 1994). Moreover, studies that have tested both the phonological loop and the VSSP using dual tasks have found that the phonological loop stays intact while the VSSP deteriorates with age (Jenkins et al., 2000; Tubi & Calev, 1989). On the other hand, research studies focussing on visual processing in the VSSP have found no age differences in the processing or storing of low-level visual-spatial information (Faubert, 2000; Faubert & Bellefeuille, 2002). Therefore, it may be that the VSSP remains intact with age for basic visual information, but deteriorates with age for complex visual information.

Based on these changes in working memory with age, some predictions can be made on the performance of older adults in visual numerosity tasks. For example, the deterioration of the central executive with age would suggest that older adults might be slower and less accurate in the counting process of visual numerosity. Although studies have found that older adults do indeed perform numerosity tasks more slowly than younger adults (e.g., Basak & Verhaeghen, 2003; Sliwinski, 1997), older adults have sometimes achieved higher accuracy levels than younger adults (e.g., Basak & Verhaeghen, 2003) and sometimes achieved lower accuracy levels than younger adults (e.g., Sliwinski, 1997). The decline in visuo-spatial functioning with age also implies that older adults may have difficulty in processing and encoding visual displays during visual numerosity, which may in turn lead to increased difficulty in storing visual displays as instances in long-term memory. However, Jenkins and Hoyer (2000) found that older adults were as impaired as younger adults when presented with new visual displays at transfer. This implies that older adults were relying on memory-based learning to the same extent as younger adults. For this to occur, the visual processing and encoding abilities of older adults must have been the same as those of the younger adults in their experiment. Therefore, it may be that the VSSP continues to function well with age for basic visual information (Faubert, 2000; Faubert & Bellefeuille, 2002).

Anxiety and Visual Numerosity Skill

No research studies were found on how anxiety may affect the acquisition of visual numerosity skill. However, since high levels of state or trait anxiety have been associated with impaired performance in a variety of skills (e.g., Leon, 1989; MacLeod & Donnellan, 1993; Markham & Darke, 1991; Tohill & Holyoak, 2000), it is likely that performance would also be impaired in visual numerosity tasks.

Furthermore, anxiety would probably interfere with working memory functioning during visual numerosity tasks. According to Ikeda et al. (1996), the negative self-talk that occurs in anxious people during skill acquisition can interfere with the functioning of the phonological loop. As a consequence, participants become distracted from their task and their performance becomes impaired (Idzikowski & Baddeley, 1983b). Since visual numerosity involves phonological loop functioning for the counting process, performance on this task is likely to be affected by anxiety.

Visual Numerosity: Conclusions

In conclusion, both young and older adults become faster at counting more than 5 items with practice, implying that they actively learn the task. However, older adults are usually slower at performing this task and can have different accuracy levels compared to younger adults. Older adults also seem to take longer to switch from algorithmic performance to automatic performance compared to younger adults (i.e., older adults have slower learning rates).

When participants are required to transfer their skill from one visual numerosity task to another, where the second task is identical to the first except for the stimuli used (i.e., different visual displays are used), the performance of both young and older adults becomes severely impaired. This implies that both age groups are learning specific visual numerosity skills during training. However, due to the lack of research in this area, it is still unclear whether the age groups transfer any general visual numerosity skill from one task to another as well.

Factors such as working memory and anxiety may also have an impact on the performance of young and older adults when learning the skill of visual numerosity. For example, since all three components of working memory seem to be involved in learning visual numerosity, then participants with smaller working memory spans may perform slower and less accurately in visual numerosity compared to participants with larger working memory spans. Furthermore, older adults would probably experience substantial impairments when performing visual numerosity tasks compared to young adults, because both the visuo-spatial sketchpad and the central executive of working memory deteriorate with age. However, the VSSP may still function well for basic visual information.

It is likely that high levels of state or trait anxiety would also have a negative impact on the performance of individuals (in terms of slower reaction times and lower levels of accuracy) in visual numerosity tasks. Furthermore, high levels of state or trait anxiety would probably interfere with working memory functioning (especially the phonological loop), which in turn, would impair skill acquisition.

General Conclusion

In conclusion, it seems that there are differences in how young and older adults acquire and transfer the skills of mental arithmetic and visual numerosity. These age differences may be related to changes that occur in working memory functioning and anxiety with age. This possibility is investigated in the experiments presented in Chapters 5 and 6.

Chapter 5: Experiment 1

The first experiment conducted for this thesis investigated whether age differences occur in the acquisition and transfer of a mental arithmetic skill, and whether age differences occur in working memory functioning and anxiety. Specifically, the aim of this experiment was to determine whether age differences in the acquisition and transfer of mental arithmetic skill were related to age differences in working memory functioning and anxiety.

From the literature review presented in Chapter 4, it seems that both young and older adults are capable of acquiring a mental arithmetic skill. Both age groups become faster with practice, and are likely to switch from slow effortful processing strategies (e.g., general algorithms) to fast and automatic processing strategies (e.g., memory retrieval) by the end of practice (e.g., Barrouillet & Fayol, 1998; Brigman & Cherry, 2002; Charness & Campbell, 1988; Greig & Speelman, 1999; Logan & Klapp, 1991; Salthouse & Coon, 1994; Salthouse & Kersten, 1993; Touron, Hoyer, & Cerella, 2001). However, young adults are usually faster at performing mental arithmetic, they have faster rates of learning, and their improvements in reaction time by the end of practice (i.e., their improvement span) are greater compared to that of older adults (e.g., Touron et al., 2001). Nevertheless, older adults can be as accurate, and sometimes more accurate at mental arithmetic than younger adults (Charness & Campbell, 1988; Salthouse & Kersten, 1993).

When participants are required to transfer mental arithmetic skill from one task to another, where the second task is identical to the first except for the stimuli used (i.e., the arithmetic problems have the same structure but use different numbers), it seems that both young and older adults can transfer some of their skill from one task to another (e.g., Charness & Campbell, 1988; Touron et al., 2001). This implies that both age groups are learning general arithmetic skills during training (Anderson, 1982). However, the fact that performance is severely impaired for both age groups at transfer suggests that they also learn specific arithmetic skills that cannot be easily transferred to a new task (Logan, 1988, 1990). Anderson's ACT* Theory (1982) can account for both the general and specific learning that occurs for each age group. According to ACT* theory, individuals initially develop item-general productions that allow them to solve arithmetic problems in a task. With practice, individuals develop item-specific productions that are specific for certain arithmetic problems. In the transfer phase, the item-specific productions developed during training are no longer appropriate, which explains why performance is slower in the initial stages of the transfer phase compared to the end stages of the training phase. However, individuals are still able to use the item-general productions developed during training, which explains why their performance in the transfer phase does not return to pre-training levels.

In terms of the Baddeley and Hitch model of working memory (1974), the phonological loop seems to be heavily involved in performing mental arithmetic (Blankenberger & Vorberg, 1997; Logie, Gilhooly, & Wynn, 1994). Indeed, it has been proposed that the phonological loop temporarily stores partial solutions to problems during mental arithmetic (Baddeley & Logie, 1999). The central executive also seems to be important in mental arithmetic, in that it can retrieve algorithms for calculating and estimating totals (Baddeley, 1966a; Baddeley & Logie, 1999; De Rammelaere, Stuyven, & Vandierendonck, 1999; Furst & Hitch, 2000; Hecht, 2002; Logie et al., 1994). On the other hand, the visuo-spatial sketchpad seems to have only a minimal involvement in mental arithmetic (Noel, Desert, Aubrun, & Seron, 2001; Trbovich & Lefevre, 2003; Wilson & Swanson, 2001).

Since the phonological loop and the central executive are so important for mental arithmetic, age-related changes in these components may affect the performance of older adults in skill acquisition. Several studies have found that the phonological loop actually remains intact with age (e.g., Dolman, Roy, Dimeck, & Hall, 2000; Jenkins, Myerson, Joerding, & Hale, 2000; Phillips & Hamilton, 2001; Rouleau & Belleville, 1996; Tubi & Calev, 1989) whereas the central executive deteriorates with age (e.g., Coffey, Wilkinson, Parashos, Soady, Sullivan, Patterson, Figiel, Webb, Spritzer, & Djang, 1992; Coleman & Flood, 1987; Craik, Morris, & Gick, 1990). This impairment in central executive functioning with age may explain why older adults perform more poorly than younger adults in complex mental arithmetic (Campbell & Charness, 1990; Oberauer, Demmrich, Mayr, & Kliegl, 2001; Oberauer, Wendland & Kliegl, 2003; Salthouse & Coon, 1994; Verhaeghen, Kliegl, & Mayr, 1997). In fact, older adults seem to have particular difficulty with hierarchical problems, which contain brackets to prevent the problems from being solved from left to right, and force individuals to solve them from the innermost brackets first. This scheduling of operations involves the use of the central executive, which presumably works less efficiently in older adults (Salthouse & Coon, 1994).

Working memory span has also been found to correlate with performance in both the initial stages of skill acquisition (Woltz, 1988) and the end stages of skill acquisition (Brigman & Cherry, 2002). This implies that working memory plays an important role in the initial stages of skill acquisition, when performance relies on the processing of information and the use of general algorithms to perform the task. However, working memory may also play an important role in the later stages of skill acquisition, in the retrieval of instances from long-term memory. These findings suggest that there is a significant relationship between working memory and skill acquisition, and that age differences in the functioning of working memory may be related to age differences in skill acquisition and transfer.

The anxiety levels of participants may also have a negative impact on the performance of individuals in mental arithmetic, in terms of slower reaction times and lower levels of accuracy. Spielberger, Gorsuch, Lushene, Vagg and Jacobs (1983) proposed that there are two types of anxiety: 'state anxiety' and 'trait anxiety'. Spielberger (1972) described state anxiety as an emotional state existing at a particular moment in time, while trait anxiety is a stable and enduring personality trait that defines how prone an individual is to being anxious. Several studies have found that individuals with high state or trait anxiety will perform more poorly on mental arithmetic tasks compared to individuals with low state or trait anxiety (e.g., Ashcraft & Faust, 1994; Hopko, McNeil, Lejuez, Ashcraft, Eifert, & Riel, 2003; Kellogg, Hopko, & Ashcraft, 1999). Furthermore, high levels of state or trait anxiety have been found to interfere with working memory functioning (e.g., Ashcraft & Kirk, 2001; Hopko, Ashcraft, & Gute, 1998; Idzikowski & Baddeley, 1983a; Idzikowski & Baddeley, 1987; Moldawsky & Moldawsky, 1952; Mueller, 1980) presumably because highly anxious individuals have a tendency to repeat negative self-statements that interfere with their phonological loop functioning and distract them from their task (Idzikowski & Baddeley, 1983b; Ikeda, Iwanaga, & Seiwa, 1996). As a consequence, highly anxious individuals become impaired during skill acquisition.

The research that has been conducted on aging and anxiety seems to suggest that trait anxiety decreases with age or, at least, remains unchanged (e.g., Bergdahl &

Bergdahl, 2002; Christensen, Jorm, Mackinnon, Korten, Jacomb, Henderson, & Rodgers, 1999; Fuentes & Cox, 2000; Henderson, Jorm, Korten, Jacomb, Christensen, & Rodgers, 1998; Nakazato & Shimonaka, 1989; Palmore, Cleveland, Nowlin, Ramm, & Siegler, 1979). This may be because older adults respond less to negative emotions, they may be better at ignoring negative emotions, or they may become more resistant to negative life events compared to younger adults (Jorm, 2000). It has also been proposed that older adults may become more psychologically stable with age (Nakazato & Shimonaka, 1989) and better able to cope with stressful situations compared to younger adults (e.g., Chiriboga & Dean, 1978; Coolidge, Segal, Hook, & Stewart, 2000; Costa, McCrae, & Arenberg, 1980). State anxiety also does not seem to be higher in older adults compared to younger adults (e.g., Fisk & Warr, 1996; Charness, Schumann, & Boritz, 1992). Therefore, older adults seem less likely to experience high levels of anxiety than younger adults during skill acquisition and transfer.

Overview of the Study

The purpose of the present experiment was primarily to investigate the issue of age differences in the acquisition and transfer of mental arithmetic skill. While this has been investigated before (e.g., Charness & Campbell, 1988; Touron et al., 2001), no study has ever looked at whether age differences in working memory functioning and anxiety are related to age differences in the acquisition and transfer of mental arithmetic. To explore this possibility, young and older adults were recruited for this study and asked to perform a complex mental arithmetic task on a computer, based on a Greig and Speelman (1999) task. In this task, participants were required to solve an algebraic equation of the form $(x^2 - y)/2$ by substituting values for x and y (e.g., $x = 1$ and $y = 3$). In the training session, values for x and y were taken from a small set of values, and each x and y pair was presented several times. In the transfer phase, participants were asked to solve the same equation, but with different x and y values. Since the same task was used in both phases, participants were able use a general algorithm to perform the task during both learning and transfer. Therefore, according to Anderson's ACT* Theory (1982), *complete* positive transfer should occur from one phase to the next. However, participants could also learn the task by storing specific solutions to problems ('instances') in their memory. If participants use this strategy, then the change of stimuli in the transfer phase would cause impairments in performance, because the solutions learned in training would not be applicable to the problems presented during transfer. Therefore, according to Logan's Instance theory (1988), *no* positive transfer should occur between the tasks in this case. On the other hand, participants could engage in both general and specific learning during training, such that their performance will be impaired at transfer, but will not return to pre-training levels (i.e., *partial* positive transfer would occur). Therefore, the amount of impairment that occurs at transfer can reveal how much positive transfer has taken place from one phase to the next.

The degree of positive transfer occurring from one phase to the next can also be measured with a technique from Speelman and Kirsner (2001). In their study, participants were divided into an experimental group and a control group and asked to perform a calculation task. During the training phase of the experiment, both groups performed the same task. However, during the transfer phase of the experiment, the experimental group was presented with a new version of the task, whereas the control group was presented with the same version of the task presented during training. The researchers found that the performance of the experimental group became impaired at transfer, whereas the performance of the control group did not. To examine transfer performance more closely, power functions were fitted to the training data of both groups, and these functions were extrapolated to predict the performance of the two groups during the transfer phase. The actual performance of the two groups during transfer was then compared to the performance predicted by their respective training phase functions. The results were that the actual performance of the control group during the initial stages of transfer fell within the 95% confidence intervals of their extrapolated training phase function. That is, the performance of the control group during transfer could be predicted from their performance during training, indicating that complete positive transfer occurred. On the other hand, the actual performance of the experimental group during the initial stages of transfer did not fall within the 95% confidence intervals of their extrapolated training phase function. Therefore, the performance of the experimental group during transfer could not be predicted from their performance during training, and thus it is assumed that no positive transfer occurred initially. However, the actual performance of the experimental group during transfer eventually fell within the 95% confidence intervals of their extrapolated training phase function. This indicates that participants in the experimental group did learn general skills during the training phase (as well as specific skills), and that they retained and used these general skills during the transfer phase (Greig & Speelman, 1999). That is, partial positive transfer occurred for the experimental group. Therefore, extrapolating a training phase function into the transfer phase, and comparing the actual transfer performance of participants with their predicted transfer performance, is a useful way of determining how much positive transfer has occurred from one task to another. This analysis procedure was used in the present experiment.

To determine the working memory span of young and older adults in this study, participants were asked to perform tasks that tapped into the processing component of their working memory, which performs calculations and manipulates incoming information, as well as the storage component of working memory, which stores the products of these calculations (Baddeley, 1986; Wechsler, 1997). To measure the storage component of working memory, the 'Digits Forward' task from the Wechsler Adult Intelligence Scale-Third Edition (Wechsler, 1997) was used and administered to participants before they began the mental arithmetic task. In this task, participants are presented with number sequences of increasing length, and must repeat the number sequences in the order in which they were presented. To measure the storage and processing components of working memory, participants were required to perform tasks in which both processing and storage were involved. One of these tasks was the 'Reading Span' task in which subjects were asked to read sentences out loud and remember the last word of the previous sentence at the same time (Daneman & Carpenter, 1980). Another of these tasks was the 'Digits Backward' task from the Wechsler Adult Intelligence Scale – Third Edition (Wechsler, 1997), where participants needed to repeat sequences of numbers in their reverse order. The mental reordering of number sequences in this task required the use of the processing component of working memory, whereas the remembering of the original number sequence required the use of the storage component of working memory. According to Daneman and Merikle (1996), tasks that measure both the storage and processing components of working memory (like Reading Span and Digits Backward Span) are actually measuring the 'functional capacity' of working memory. That is, a small working memory capacity in an individual is often an indicator of inefficient processing, such that the individual has to allocate more resources to the processing component of working memory, thus leaving fewer resources to the storage component of working memory. Therefore, individuals with smaller working memory spans (as measured by Reading Span and Digits Backward Span) have less functional processing capacities, and as a consequence, smaller storage capacities. To determine the functional capacities of individuals in our experiment, both the Reading Span and Digits Backward tasks were administered to participants before they commenced the mental arithmetic task.

To measure the anxiety of participants during this experiment, each participant was required to complete the State-Trait Anxiety Inventory (Spielberger et al., 1983). The state anxiety component of this inventory was divided into two questionnaires, so that one half could be administered before the training phase of the mental arithmetic task, and the other half could be administered after the training phase. This allowed any changes in state anxiety to be detected as the experiment progressed. On the other hand, the trait anxiety component of the inventory was administered in its original form, before the commencement of the mental arithmetic task. It was decided to measure both the state and trait anxiety of individuals, since high levels of either one can have a negative impact on the performance of individuals.

Based on the research cited in this chapter regarding aging, the acquisition and transfer of mental arithmetic, working memory, and anxiety, it was hypothesised that:

- Young and older adults will become significantly faster in their performance of mental arithmetic, from the beginning to the end of each learning phase.

- The graphs of reaction time against practice for both age groups during each phase of the mental arithmetic task will resemble power or exponential functions.
- Older adults will be consistently slower than younger adults when performing the mental arithmetic task, during each phase of the task.
- The effect of practice on reaction times will be greater for young adults than for older adults, during each phase of the mental arithmetic task.
- The learning rate (determined by the 'c' parameter of learning functions) will be faster for young adults than for older adults in each phase of the mental arithmetic task.
- The amount of improvement (in reaction time) that occurs from the beginning to the end of each phase of the mental arithmetic task will be greater for young adults than for older adults.
- The level of accuracy will be approximately equal for young and older adults during both phases of the mental arithmetic task.
- Both young and older adults will demonstrate partial positive transfer in the mental arithmetic task.
- Measures of working memory will correlate positively with accuracy and negatively with reaction time during both phases of the mental arithmetic task. That is, higher working memory spans will be associated with higher levels of accuracy and lower reaction times in mental arithmetic.
- Young and older adults will perform equally well on the Digits Forward task, because this task measures the storage component of working memory (in particular, the phonological loop), which presumably stays intact with age.

- Older adults will perform more poorly on the Reading Span task and the Digits Backwards task compared to younger adults. This is because these tasks involve central executive functioning, which is thought to deteriorate with age.
- Measures of state and/or trait anxiety will correlate negatively with the performance of individuals during both phases of the mental arithmetic task. That is, the higher the state/trait anxiety, the poorer the performance in terms of reaction time and accuracy.
- Measures of state and/or trait anxiety will correlate negatively with measures of working memory. That is, the higher the state/trait anxiety, the lower the working memory spans of individuals.
- Measures of state anxiety will not be significantly different for young and older adults, but measures of trait anxiety will be significantly higher for young adults than for older adults.

As well as testing these hypotheses, the present experiment aims to clarify some of the issues that remain unresolved in the aging, skill acquisition and transfer literature. For example, it is unclear whether older adults show the same amount of positive transfer in mental arithmetic skill as younger adults. A difference in the amount of positive transfer for each age group would imply that young and older adults learn mental arithmetic tasks in a different way, and perhaps rely on general and specific skills to different extents. Furthermore, it is uncertain whether young and older adults recover in the same way during the transfer phase of a mental arithmetic task. For example, it may be that young and older adults differ in their amount of initial recovery in the transfer phase (i.e., the mean difference in reaction time between the first two practice blocks of transfer) and in their speed of recovery in the transfer phase (i.e., how long it takes for participants to return to their final training phase reaction time during the transfer phase). It is likely that working memory functioning plays a vital role in the initial stages of the transfer phase, since participants need to revert to using general algorithmic computations in order to solve new arithmetic problems. Therefore, age differences in the amount of initial recovery and speed of recovery may be related to age differences in working memory functioning. However, anxiety may also be a factor contributing to the recovery performance of young and older adults during the transfer stage. It is hoped that the results of Experiment 1 will shed some light on these issues.

Method

Research Design

This experiment was organized into four parts. In the first part, anxiety questionnaires and working memory measures were administered. In the second part, participants completed the first phase (training) of the computer task. In the third part, a state anxiety questionnaire was administered followed by a 5-minute break. Finally in the fourth part, participants completed the second phase (transfer) of the computer task.

The experiment comprised of four experimental groups – two groups of young participants and two groups of older participants. This allowed the presentation of stimulus items to be counterbalanced across the two phases of the experiment, for both young and older participants.

The computer task followed an AB design, whereby participants completed the training phase (which used one set of items) followed by the transfer phase (which used a different set of items).

Participants

This experiment used a convenience sample of 48 young and 48 older participants. The young participants were undergraduate students from Edith Cowan University, recruited through advertising on university notice boards. The older participants were volunteers from a community organisation called the Positive Aging Foundation. Data from two young participants and five older participants were discarded because the learning criterion was not reached in each case. The learning criterion was defined as an accuracy rate of at least 70% in each of the training and transfer phases. This cut-off point separated the participants who understood the task and performed the task faster with practice, from those who failed to understand and learn the task. The exclusion of these participants left 46 young participants and 43 older participants.

Of the 46 young participants, 11 were male and 35 were female. They were aged between 17 and 25 years (M = 19.37 years), had 11 to 17 years of formal education (M = 13.16 years), 95.7% were native English speakers, 87.0% denied taking medications causing drowsiness, and 93.5% denied having health problems affecting performance. The participants were randomly assigned to one of two experimental groups to enable the counter-balancing of stimulus items in the two phases of the experiment. Each group contained 23 participants.

Of the 43 older participants, 20 were male and 23 were female. They were aged between 65 and 75 years (M = 69.4 years), had 7 to 35 years of formal education (M = 12.2 years), 95.3% were native English speakers, 86.0% denied taking medications causing drowsiness, and 83.7% denied having health problems affecting performance. Information about their past occupations is summarized in Table A1 (Appendix A). The number of years since they retired from full-time work ranged from 0 to 20 years (M = 8.95 years). These participants were assigned in a random fashion to one of two experimental groups to allow the counterbalancing of stimulus items in the two phases of the experiment. Group one contained 22 participants while group two contained 21 participants.

Apparatus/Materials

A number of self-report measures were used in this experiment. To measure the state and trait anxiety of individual participants, the STAI (Spielberger et al., 1983) was administered during each testing session. This measurement tool has been used in past research to measure how anxiety affects learning and test performance. The state anxiety component of this tool normally consists of 20 items, but for this experiment it was divided into two 10-item questionnaires (see Appendix B). This was done so that state anxiety could be measured both before and after the training phase of the computer task. The trait anxiety component consists of 20 items and was not altered for this experiment (see Appendix C). The scoring instructions for these tests are found in Appendix D. High scores in either the state anxiety component or trait anxiety component of the STAI indicate high levels of anxiety. The STAI has acceptable reliability and validity (Spielberger et al., 1983).

To determine the working memory spans of individuals, the Digit Span Task from the Wechsler Adult Intelligence Scale - 3rd Edition (Wechsler, 1997) was administered to each participant (see Appendix E). This task is made up of a Forward

Digit Span component that measures maximum working memory storage, and a Backward Digit Span component that measures mental manipulation and storage in working memory (Wechsler, 1997). The standardised instructions for this task were taken from the WAIS-III Scoring and Administration Manual (See Appendix F). In the Forward Digit Span component, participants were presented with 16 sequences of numbers, organised into 8 sets (i.e., each set contained two number sequences). The sequences of numbers increased in length with each set, and participants received one point for each sequence correctly recalled. If participants failed to recall both sequences in a set, the task was discontinued. The total score for Digits Forward was obtained by tallying up the scores for each set. In the Backward Digit Span component, participants were presented with 14 sequences of numbers, organised into 7 sets (i.e., each set contained two number sequences). Again, the sequences of numbers increased in length with each set, and a score of one point was given for each sequence correctly recalled. If participants failed to recall both sequences in a set, the task was discontinued. The total score for Digits Backward was obtained by tallying up the scores for each set. The Digit Span Task has good reliability and validity, and a factor loading of .71 on Working Memory (Wechsler, 1997).

The Reading Span task (Daneman & Carpenter, 1980) was another tool used to measure working memory span. This task has significant correlations with reading ability and mathematical processes (Daneman & Merickle, 1996). The task involves the administration of 60 distinct sentences of 13-16 words in length, with each sentence ending in a different word (see Appendix G). Each sentence was typed as a single line on an A4 piece of paper in Times New Roman, size 16 font, and inserted into an A4 spiral-bound presentation book. The presentation book was organised according to sentence sets, whereby the end of a set was indicated by a blank piece of

A4 coloured paper. The first two sets in the book contained 2 sentences each and were used as practice exercises. For each practice set, participants were asked to read the sentences out loud and to recall the last word of each sentence. The instructions given to participants were taken from Daneman and Carpenter (1980, see Appendix H). If participants were comfortable with the task, they were presented with the rest of the sentences (i.e., three sets of 2, 3, 4, 5 and 6 sentences). Again, participants were asked to read out loud each sentence in a set and to then recall the last word of each sentence. The number of sentences that made up a set was called the sentence level. If participants failed to remember the last word of one sentence in a set, this was considered a failed set at that level. The administration of the test continued until participants were no longer able to get 2 out of 3 sets correct at a particular level. The level at which they were able to get 2 out of 3 sets correct was interpreted as their Reading Span score.

Finally, a mental arithmetic task was used as the main skill acquisition task of this experiment. This task was a modified version of the one used by Greig and Speelman (1999). The instructions, task, and feedback were presented on four Apple Macintosh G3 computers with 17-inch monitors and standard keyboards (See Appendix I for instructions). Each computer was located in an individual sound-proof room. SuperLab Pro Version 1.74 was used to present the stimuli to the participants and to record their keyboard responses.

In the mental arithmetic task, participants were asked to solve an algebraic equation in which they had to find the value of 'A' for given values of x and y. An example of this equation is given in Figure 2. Participants were asked to respond using a standard keyboard with the 'Z' key labelled 'O' for 'odd' and the '/' key

$$\frac{x^2 - y}{2} = A$$

$$x = 3 \qquad y = 5$$

Figure 2. Example of the algebra equation displayed on the computer screen.

labelled 'E' for 'even'. They were instructed to press 'O' if the value of A was an odd number, and to press 'E' if the value of A was an even number. The instructions emphasised the importance of responding with speed as well as accuracy. The participants were then given eight practice trials of the task. These practise trials had x and y value combinations that were not used in the actual experiment (see Table 1). Each practice trial was presented once only, and with the experimenter nearby in case the participant had any questions. When a participant responded on the keyboard, their response was always followed by feedback on the screen about whether they were correct or not. Participants were informed to 'press the space bar' in order to start the next trial.

After the practice phase, the mental arithmetic task involved a training phase and a transfer phase. The items used in the training phase were different to those used in the transfer phase. In each phase, eight item pairs were used. Each item pair consisted of a value for x (ranging from 5-8) and a value for y (ranging from 1-16). Therefore the solutions for A were always between 5 and 31. The item sets used in each phase were approximately equal in difficulty. Table 2 shows the item sets that were used in this experiment.

Procedure

Participants were tested in individual computer rooms. At the start of the experiment they were asked to read and sign an informed consent form, which gave general information about the experiment and its testing procedures, as well as ethical issues (see Appendix J).

Participants were then asked to complete both the State and Trait components of the STAI (Spielberger et al., 1983). A 10-item shortened version of the State

Table 1.

Practice Items: Values for x and y, the resultant answer (A) and the appropriate keypad response when values are substituted into the equation.

x	y	A	Response
3	1	4	EVEN
3	3	3	ODD
3	5	2	EVEN
3	7	1	ODD
4	2	7	ODD
4	4	6	EVEN
4	6	5	ODD
4	8	4	EVEN

Table 2.

Item Sets 1 and 2: Values for x and y, the resultant answer (A) and the appropriate keypad response when values are substituted into the equation.

Set 1				Set 2			
x	*y*	*A*	Response	*x*	*y*	*A*	Response
5	9	8	EVEN	6	10	13	ODD
5	11	7	ODD	6	12	12	EVEN
5	13	6	EVEN	6	14	11	ODD
5	15	5	ODD	6	16	10	EVEN
8	2	31	ODD	7	1	24	EVEN
8	4	30	EVEN	7	3	23	ODD
8	6	29	ODD	7	5	22	EVEN
8	8	28	EVEN	7	7	21	ODD

component was administered prior to the Trait component, as recommended by Spielberger et al. (1983). The other 10-item version of the State component was administered later in the session. The administration of the two 10-item versions of the State questionnaires was counterbalanced across participants, so that half of the participants were given the STAI-1 first and the STAI-2 later, while the other half were given the STAI-2 first and the STAI-1 later.

The Digit Span Task subtest from the WAIS-III (Wechsler, 1997) was then administered verbally by the experimenter, followed by the Reading Span Task (Daneman & Carpenter, 1980). Then the practice and training phases of the computer generated algebra task were administered.

During the training phase of the algebra task, participants were presented with 30 blocks of eight trials (i.e., 240 trials). The eight trials corresponded to the 8 pairs of x and y values from either Set 1 or Set 2 (see Table 2). Therefore, each x and y pair was presented 30 times during training. The Superlab software allowed the x and y pairs to be presented in a random order within each block.

Following the training phase of the computer task, participants were asked to complete the second 10-item State Anxiety questionnaire from the STAI. This was done to assess changes in their state anxiety as the experiment progressed. When this questionnaire was completed, participants were given a 5-minute break with tea or coffee.

After the short break, participants were asked to complete the transfer phase of the computer task. During the transfer phase, participants were given another 30 blocks of eight trials. Each block used the x and y pairs from the Set not used in the training phase (see Table 2). Again, the x-y pairs were presented in a random order within each block. The items presented in the training and transfer phases were counterbalanced in this experiment so as to control for possible differences in the item difficulty of the two sets. Therefore, half of the participants in each age group were presented with Set 1 items during the training phase and Set 2 items during the transfer phase, while the other half of the participants in each age group were presented with the opposite order.

When participants finished the transfer phase of the algebra task, they were asked to fill out a participant detail sheet to obtain demographic information (see Appendix K).

Results

The results of this experiment were analysed using Microsoft Excel 2000 and SPSS 11.0 software for Windows. Only the reaction times from correct trials were used for analysis. The mean reaction times and standard deviations of young participants on the algebra task from Block 1 to 30 (training) and Block 31 to 60 (transfer) are shown in Table L1 and Table L2 (Appendix L). The mean reaction times and standard deviations of older participants from Block 1 to 30 (training) and Block 31 to 60 (transfer) are shown in Table M1 and Table M2 (Appendix M). Mean reaction times for young and older participants are presented in Figure 3. All statistical tests performed on the data were two-tailed tests with $\alpha = 0.5$.

Young Participants: Practice and transfer effects

During the training phase, the average accuracy was 92.8%, whereas during the transfer phase it was 90.5%. The mean reaction times and standard deviations for Block 1, Block 2 and Block 30 in the training phase; and Block 31, Block 32 and Block 60 in the transfer phase, are presented in Table 3.

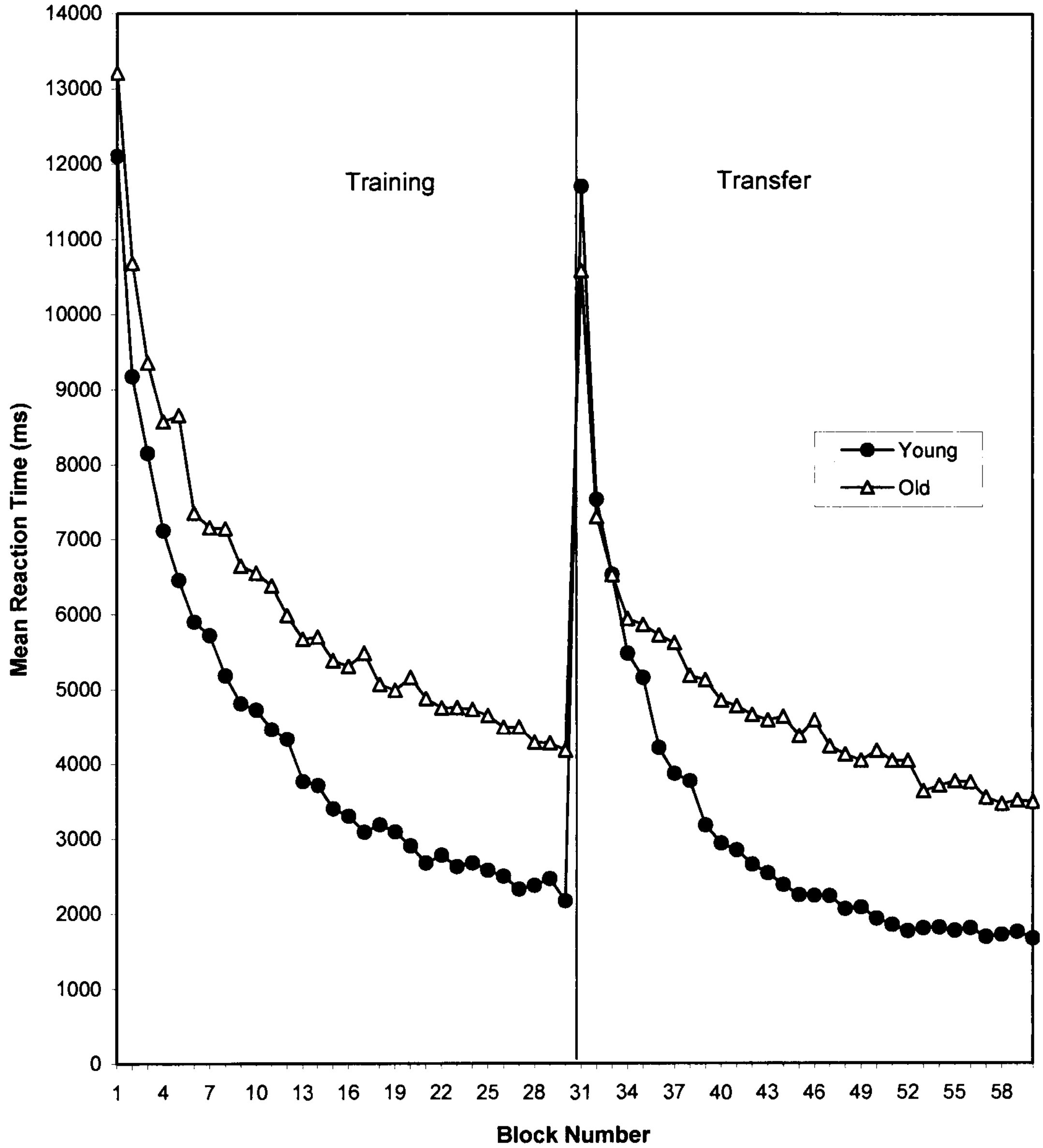

Figure 3. Mean reaction times (ms) for young and older participants during training and transfer.

Table 3.

Mean Reaction Times and Standard Deviations for Blocks in the Training Phase and the Transfer Phase for the Young Participants.

Block Number	Mean Reaction Time (ms)	Standard Deviation (ms)
Block 1	12103	6511
Block 2	9175	4535
Block 30	2165	1164
Block 31	11703	10979
Block 32	7531	4655
Block 60	1665	957

A within-subjects repeated measures ANOVA demonstrated a significant reduction in response time from Block 1 to Block 2, $F(1,45) = 29.47, p < .001$; and from Block 1 to Block 30, $F(1,45) = 127.766, p < .001$. Similarly, response time decreased significantly in the transfer phase from Block 31 to Block 32, $F(1,45) = 10.479, p < .05$; and from Block 31 to Block 60, $F(1,45) = 39.176, p < .001$. Within-subjects repeated measures ANOVAs revealed a significant effect of practice in both the training phase, $F(1,29) = 138.057, p < .001$, and the transfer phase, $F(1,29) = 73.472, p < .001$.

Within-subjects repeated measures ANOVAs were used to determine whether transfer occurred from the training phase to the transfer phase. The response time for participants was significantly slower in Block 31 than in Block 30, $F\ (1,45) = 38.99$, $p < .001$, so much so that the mean response time in Block 31 did not differ significantly from the mean response time in Block 1. This suggests that no positive transfer occurred from the training phase to the transfer phase.

However, theories of skill acquisition suggest that some transfer occurs if performance in the transfer phase can be predicted by extrapolating power functions that describe skill acquisition in the training phase (Speelman & Kirsner, 1997). Therefore, a power function of the form $\mathrm{RT} = \mathrm{a} + \mathrm{bP}^{-\mathrm{c}}$ (where 'RT' is reaction time, 'P' is the number of blocks of practice, and 'a', 'b' and 'c' are performance parameters) was fitted to the training data and extrapolated to predict transfer performance (using Microsoft Excel). An exponential function of the form $\mathrm{RT} = \mathrm{a} + \mathrm{be}^{-\mathrm{cP}}$ (where 'RT' is reaction time, 'P' is the number of blocks of practice, 'e' is the exponential base, and 'a', 'b' and 'c' are performance parameters) was also fitted to the training data, to determine if it was a better fit than the power function. The parameters of the fitted functions and two measures of goodness of fit (r^2 and *rmsd*, the root mean squared deviation between predicted and observed values) are presented in Table 4. An attempt was made initially to fit functions with non-zero asymptotes (i.e., 'a' values other than zero) to the data. However, functions with zero asymptotes always provided better fits to the data. Table 4 illustrates that the power function had a higher r^2 value and lower *rmsd* value compared to the exponential function. Therefore, the power function provided a better fit to the training data.

To determine whether performance in the transfer phase deviated significantly from that which could be predicted by extrapolating from performance in the training phase, confidence intervals ($\alpha = .05$) were calculated for the transfer phase data. The observed reaction times for the training and transfer phases, the power function for the training phase (also extrapolated into the transfer phase), and the 95% confidence intervals for all the data, are shown in Figure 4. From this figure it seems that the young participants returned to their original learning curve by Block 45 of the transfer phase. That is, Block 45 is the first block where the confidence interval and extrapolated training power function intersected.

Older Participants: Practice and transfer effects

The average accuracy during the training phase was 94.0%, whereas during the transfer phase it was 93.3%. The mean reaction times and standard deviations for Block 1, Block 2 and Block 30 in the training phase; and Block 31, Block 32 and Block 60 in the transfer phase, are presented in Table 5.

A within-subjects repeated measures ANOVA demonstrated a significant reduction in response time from Block 1 to Block 2, $F(1,42) = 11.691, p < .05$; and from Block 1 to Block 30, $F(1,42) = 112.733, p < .001$. Similarly, response time decreased significantly in the transfer phase from Block 31 to Block 32, $F(1,42) =$

Table 4.

Parameters and Measures of Goodness of Fit for the Power Function and Exponential Function Fitted to Mean Reaction Times of Young Participants for the Training Phase.

	Fitted parameters			Goodness of fit	
	a	*b*	*-c*	r^2	*rmsd*
Power function	0	14386.0	0.5273	.9785	497.65
Exponential function	0	8318.7	0.0493	.9174	898.51

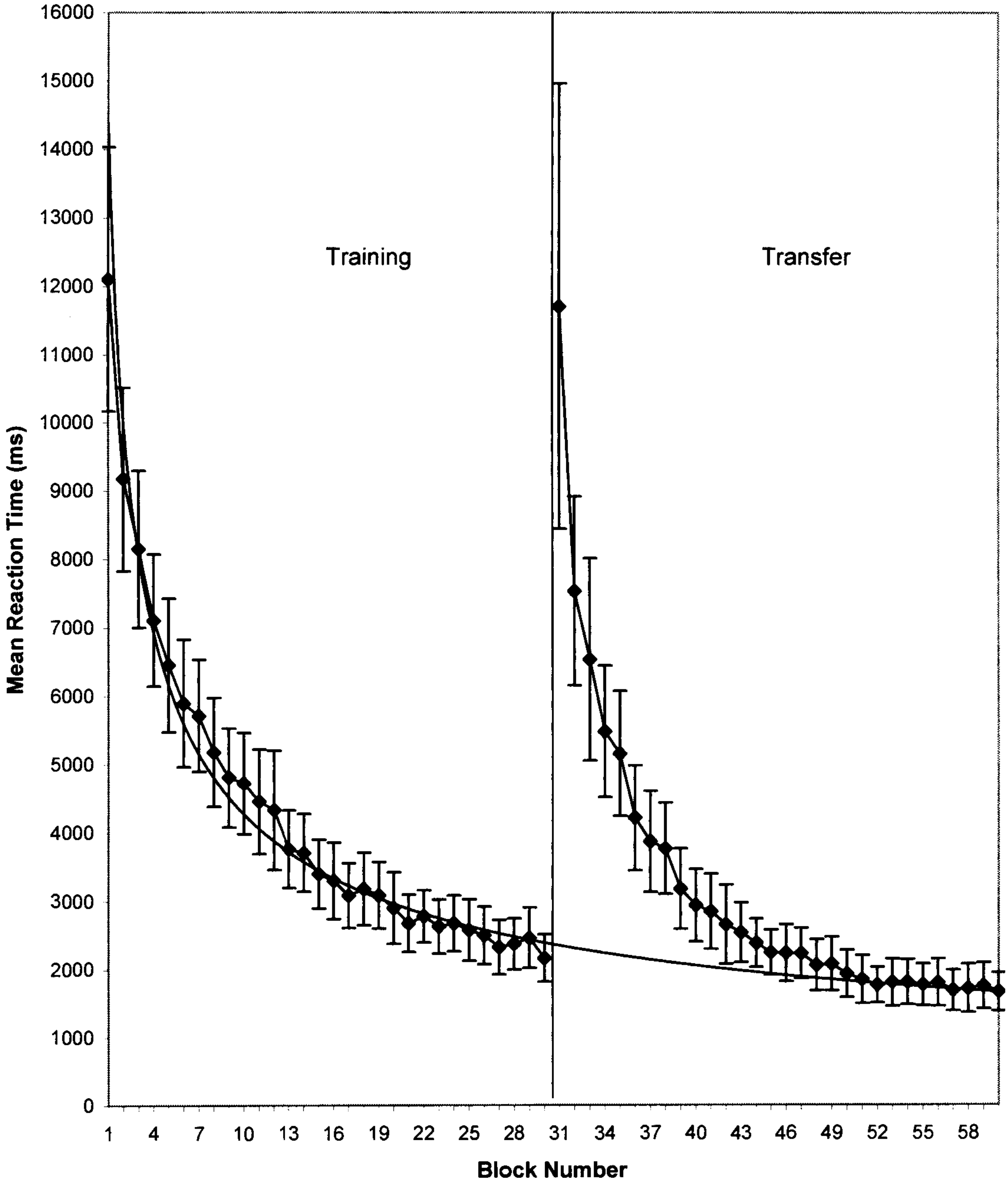

Figure 4. Observed reaction times for training and transfer with 95% confidence intervals, and fitted power function extrapolated to transfer phase, for the young participants.

Table 5.

Mean Reaction Times and Standard Deviations for Blocks in the Training Phase and the Transfer Phase for the Older Participants.

Block Number	Mean Reaction Time (ms)	Standard Deviation (ms)
Block 1	13207	6230
Block 2	10679	5730
Block 30	4182	1560
Block 31	10580	5467
Block 32	7294	3453
Block 60	3485	1133

62.552, $p < .001$; and from Block 31 to Block 60, $F(1,42) = 79.350$, $p < .001$. Within-subjects repeated measures ANOVAs revealed a significant effect of practice in both the training phase, $F(1,29) = 138.057$, $p < .001$, and the transfer phase, $F(1,29) = 73.472$, $p < .001$.

Within-subjects repeated measures ANOVAs were used to determine whether transfer occurred from the training phase to the transfer phase. The response time for participants was significantly slower in Block 31 than in Block 30, $F(1,42) = 60.149$, $p < .001$, although response time in Block 31 was still significantly faster than in Block 1, $F(1, 42) = 11.620$, $p < .05$. This indicates that positive transfer did occur from the training phase to the transfer phase.

A power function of the form $RT = a + bP^{-c}$ (where 'RT' is reaction time, 'P' is the number of blocks of practice, and 'a', 'b' and 'c' are performance parameters) was fitted to the training data and extrapolated to predict transfer performance using Microsoft Excel. An exponential function of the form $RT = a + be^{-cP}$ (where 'RT' is reaction time, 'P' is the number of blocks of practice, 'e' is the exponential base, and 'a', 'b' and 'c' are performance parameters) was also fitted to the training data, to determine if this function was a better fit than the power function. The parameters of the fitted functions and two measures of goodness of fit (r^2 and *rmsd*, the root mean squared deviation between predicted and observed values) are presented in Table 6. Again, functions with zero asymptotes were found to provide better fits to the data than functions with non-zero asymptotes. The higher r^2 value and lower *rmsd* value for the power function in Table 6 suggests that this function is a better fit for the training data compared to the exponential function.

To determine whether performance in the transfer phase deviated significantly from that which could be predicted by extrapolating from performance

Table 6.

Parameters and Measures of Goodness of Fit for the Power Function and Exponential Function Fitted to Mean Reaction Times of Older Participants for the Training Phase.

	Fitted parameters			Goodness of fit	
	a	*b*	*-c*	r^2	*rmsd*
Power function	0	13825.0	0.3405	.9902	214.71
Exponential function	0	9581.5	0.0310	.8804	878.86

in the training phase, confidence intervals ($\alpha = .05$) were calculated for the transfer phase data. The observed reaction times for the training and transfer phases, the power function for the training phase (extrapolated into the transfer phase), and the 95% confidence intervals for all the data, are shown in Figure 5. From this figure, it seems that the older participants returned to their original learning curve by Block 48 of the transfer phase.

Age group differences: Practice and transfer effects

A within-participants repeated measures ANOVA found a significant main effect of age on reaction time, for both the training phase, $F(1,29) = 20.871, p < .001$, and the transfer phase, $F(1,29) = 22.898, p < .001$. This suggests that the young participants were consistently and significantly faster than the older participants during both phases of the experiment. The analysis also found a block X age interaction in the transfer phase only, $F(1,29) = 3.751, p < .001$. Inspection of Figure 3 suggests that this interaction was such that the young improved with practice to a greater extent than the older participants.

The learning rates of young and older participants were obtained by looking at the parameters of the learning curves. Touron et al. (2001) stated that in the power function $RT = a + bP^{-c}$ (where 'RT' is response time and 'P' is the number of practice trials), the 'a' parameter represents the asymptotic performance, the 'b' parameter represents improvement span, and the 'c' parameter represents learning rate (or rate of change). From Table 4 and Table 6, it is clear that $c = 0.5273$ for the young age group, while $c = 0.3405$ for the older age group. To determine what the best-fitting functions were for the performance of young and older adults during the transfer phase, Microsoft Excel software was used. The parameters of

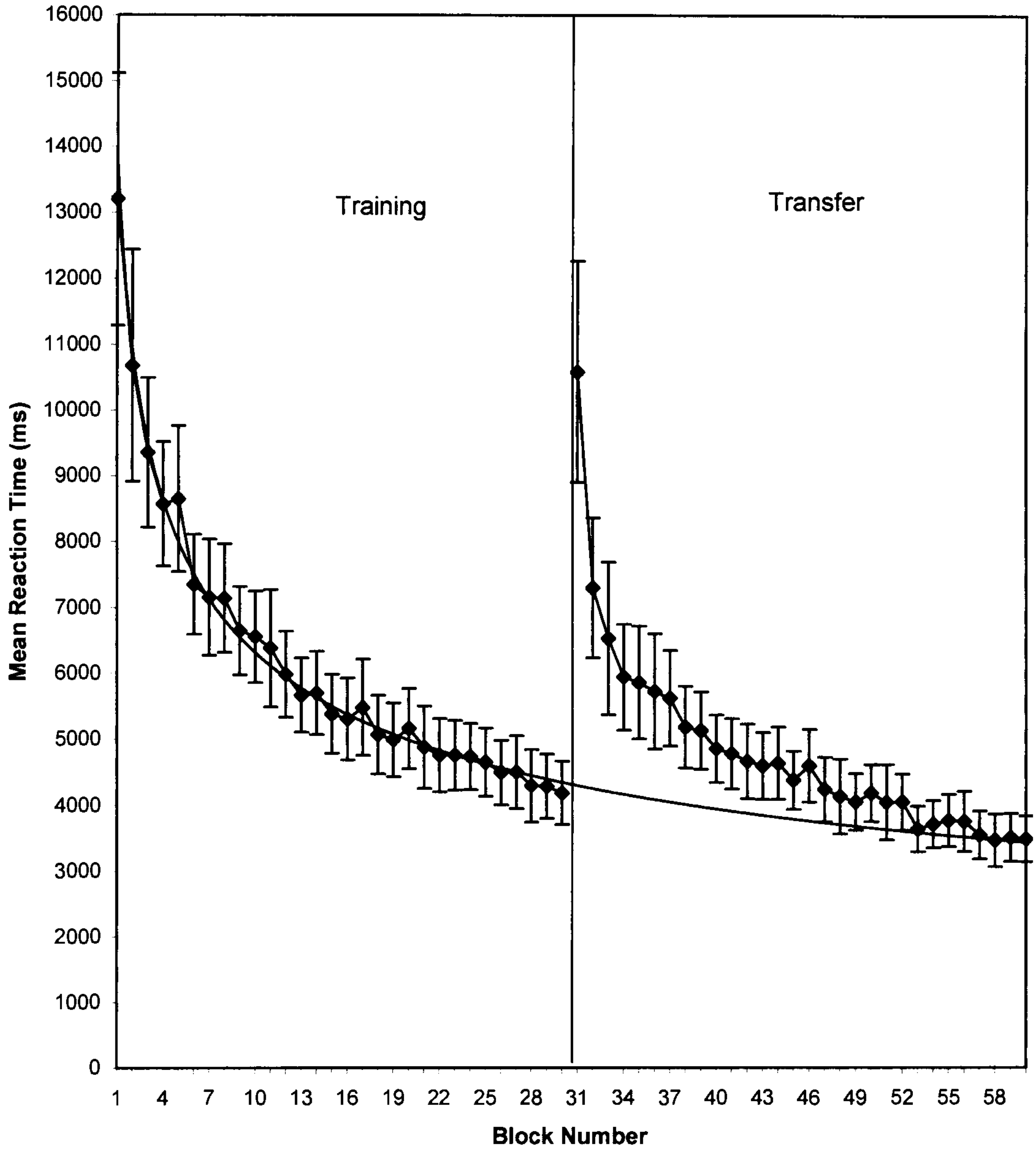

Figure 5. Observed reaction times for training and transfer with 95% confidence intervals, and fitted power function extrapolated to transfer phase, for the older participants.

these transfer phase functions and measures of goodness of fit (r^2 and *rmsd*, the root mean squared deviation between predicted and observed values) for young and older adults are presented in Table 7. For both age groups, power functions had higher r^2 values and lower *rmsd* values, which suggests that they provided better fits to the data than exponential functions. Since the parameter 'c' in power functions represents the learning rate or the rate of change (Touron et al., 2001), it is clear from Table 7 that the younger adults had a faster learning rate (c = 0.5989) compared to older adults (c = 0.2919) during the transfer phase as well. Interestingly, the learning rate for younger adults actually improved during transfer compared to training, whereas the learning rate for older adults declined during transfer.

The improvement span of each age group was also analysed. This refers to the amount of improvement in reaction time brought about by practice. To examine this, the difference in reaction time between Block 30 and Block 1 was found for each participant, as well as the difference in reaction time between Block 60 and Block 31. Independent samples t-tests were then used to compare the mean differences for each age group. The result was that there was no significant difference in improvement span in young participants compared to older participants, in either phase of the experiment.

To determine whether the amount of positive transfer differed significantly between age groups, the difference in reaction time between Block 31 and Block 30 was found for each participant. An independent samples t-test was used to compare the mean differences of the two groups. There was no significant difference between the two means. A one-way repeated-measures ANOVA also found no significant effect of age on amount of transfer, and no significant block X age interaction.

Table 7.

Parameters and Measures of Goodness of Fit for the Transfer Phase Functions of Young and Older Participants.

	Fitted parameters			Goodness of fit	
	a	*b*	*-c*	r^2	*rmsd*
	Young Participants (n = 46)				
Power function	0	12090.0	0.5989	.9917	182.90
Exponential function	0	6190.1	0.0530	.8311	1208.74
	Older Participants (n = 43)				
Power function	0	9579.8	0.2919	.9750	261.72
Exponential function	0	6947.0	0.0261	.8373	751.32

However, an ANCOVA revealed that when performance at Block 30 is statistically controlled for, there is a significant effect of age on reaction times at Block 31, $F(1,89) = 7.651, p = .007$, such that older adults experienced a smaller decline in reaction time (from Block 30 to Block31) compared to younger adults. This suggests that the amount of positive transfer was greater for older adults than for younger adults.

To determine whether the amount of initial recovery in the transfer phase differed significantly between age groups, the difference in reaction time between Block 32 and Block 31 was found for each participant. An independent samples t-test was used to compare the mean differences of the two groups. There was no significant difference between the two means.

Similarly, there was no difference between young and older participants in the speed of recovery in the transfer phase. Both young and older participants returned to their Block 30 reaction time by Block 48 of the transfer phase (see Figure 4 and Figure 5).

Age group differences: Working memory measures

To determine the correlations between variables, the Pearson *r* (two-tailed) correlation coefficient was found. The intercorrelations between working memory measures (WM) for young and older participants are displayed in Table 8.

To determine whether a relationship existed between working memory and performance (i.e., reaction time), correlations were performed between working memory measures and each block of performance during the training and transfer phases. For the young participants, the general finding was that working memory measures did not correlate with performance during the training phase. The only

Table 8.

Intercorrelations Between Digits Forward (Digits F), Digits Backward (Digits B), Digit Span Total (Digit Span) and Reading Span, for Young and Older Participants.

WM Measures	Digits F	Digits B	Digit Span	Reading Span
		Young Participants (n = 46)		
Digits F	-	.61**	.90**	.37*
Digits B	-	-	.89**	.29*
Digit Span	-	-	-	.37*
		Older Participants (n = 43)		
Digits F	-	.40**	.83**	.51**
Digits B	-	-	.84**	.21
Digit Span	-	-	-	.43**

*$p < .05$ **$p < .01$.

significant correlation occurred between the Digits Backward measure and Block 26 reaction times ($r = -.296, p = .04$). However, working memory measures did correlate a great deal with performance during the transfer phase. In the first third of the transfer phase (Blocks 31 to 40) significant correlations were found between working memory and 3 reaction time blocks; in the middle third of the transfer phase (Blocks 41 to 50) significant correlations were found between working memory and 7 reaction time blocks; and in the last third of the transfer phase (Blocks 51 to 60) significant correlations were found between working memory and 7 reaction time blocks. The significant correlations between working memory measures and performance during transfer are presented in Table 9. In all cases, the direction of these correlations indicated that the larger a participant's working memory capacity, the faster their performance on the arithmetic task. In contrast, no significant correlations were found between working memory measures and reaction time during either phase of the experiment for older adults.

Independent-samples t-tests revealed that mean scores for Digits Forward and Reading span were not significantly different between the two age groups. However, the mean score for Digits Backward in the young group ($M = 7.17$) was significantly higher than the mean score in the older group ($M = 6.33$), $t\ (87) = 2.085, p = .04$. The mean scores and standard deviations of the working memory measures are found in Table N1 (Appendix N).

Age group differences: Anxiety measures

For both the young and older age groups, the two measures of state anxiety (STAI-1 and STAI-2) correlated positively with each other, as well as with the Trait Anxiety measure (see Table 10).

Table 9.

Significant Correlations Between Measures Of Working Memory and Mean Block Reaction Times for Young Participants During Transfer.

	Working Memory Measures		
Block Number	Digits F	Digits B	Reading Span
	Young Participants (n = 46)		
37	-.18	-.30*	-.29*
38	-.17	-.34*	-.25
40	-.04	-.22	-.30*
43	-.22	-.31*	-.34*
44	-.30*	-.34*	-.38**
45	-.15	-.34*	-.13
46	-.24	-.38**	-.19
48	-.18	-.37*	-.12
49	-.18	-.35*	-.14
50	-.20	-.41**	-.05
51	-.20	-.30*	-.16
53	-.15	-.31*	-.04
54	-.14	-.34*	-.09
56	-.22	-.38**	-.12
57	-.26	-.34*	-.23
59	-.26	-.33*	-.19
60	-.21	-.34*	-.11

*$p < .05$ **$p < .01$.

Table 10.

Intercorrelations Between Anxiety Measures for Young and Old Participants

Anxiety Measures	STAI-1	STAI-2	Trait Anxiety
	Young Participants (n = 46)		
STAI-1	-	.45**	.60**
STAI-2	.45**	-	.52**
	Old Participants (n = 43)		
STAI-1	-	.53**	.67**
STAI-2	.53**	-	.58**

**$p < .01$.

To determine whether a relationship existed between anxiety and performance (i.e., reaction time), correlations were performed between anxiety measures and each block of performance during the training and transfer phases. For the young participants, anxiety measures correlated a great deal with performance during the training phase, such that the more anxious a participant was, the slower their performance was on the arithmetic task. In the first third of the training phase (Blocks 1 to 10), anxiety scores correlated significantly with 3 reaction time blocks; in the second third of the training phase (Blocks 11 to 20) anxiety scores correlated significantly with 4 reaction time blocks; and in the last third of the training phase (Blocks 21 to 30) anxiety scores correlated significantly with 9 reaction time blocks. The significant correlations between anxiety measures and performance during training are presented in Table 11. Anxiety was correlated with performance during the transfer phase of the experiment in the same way, but to a lesser extent than in training. In the first third of the transfer phase (Blocks 31 to 40), significant correlations were found between anxiety measures and 1 reaction time block; in the middle third of the transfer phase (Blocks 41 to 50) significant correlations were found between anxiety measures and 5 reaction time blocks; and in the last third of the transfer phase (Blocks 51 to 60) significant correlations were found between anxiety measures and 3 reaction time blocks. The significant correlations between anxiety measures and the performance of young adults during transfer are presented in Table 12.

The performance of older adults during each phase of the experiment was also associated with measures of anxiety, such that the higher the anxiety of individuals, the slower their reaction times during mental arithmetic. In the first third of the training phase (Blocks 1 to 10) anxiety scores correlated significantly with 7

Table 11.

Significant Correlations Between Measures Of Anxiety and Mean Block Reaction Times for Young Participants During the Training Phase.

	Anxiety Measures		
Block Number	STAI-1	STAI-2	Trait
	Young Participants (n = 46)		
4	.30*	.15	.14
5	.31*	.10	.09
6	.33*	.22	.17
15	.30*	.25	.13
17	.28	.31*	.22
19	.18	.41**	.21
20	.30*	.30*	.14
21	.32*	.39**	.30*
23	.30*	.34*	.27
24	.22	.39**	.20
25	.15	.29*	.24
26	.14	.38**	.24
27	.21	.42**	.24
28	.22	.36*	.21
29	.21	.38**	.28
30	.16	.46**	.25

*$p < .05$ **$p < .01$.

Table 12.

Significant Correlations Between Measures Of Anxiety and Mean Block Reaction Times for Young Participants During the Transfer Phase.

	Anxiety Measures		
Block Number	STAI-1	STAI-2	Trait
	Young Participants (n = 46)		
40	.26	.30*	.35*
42	.30*	.34*	.33*
43	.26	.27	.35*
44	.30*	.26	.32*
47	.20	.35*	.22
48	.24	.27	.31*
57	.24	.27	.32*
59	.21	.32*	.27
60	.12	.30*	.23

*$p < .05$ **$p < .01$.

reaction time blocks; in the middle of the training phase (Blocks 11 to 20) anxiety scores correlated significantly with 7 reaction time blocks; while in the last third of the training phase (Blocks 21 to 30) anxiety scores correlated significantly with all 10 reaction time blocks. The significant correlations between anxiety measures and the performance of older adults during training are presented in Table 13. A similar association between anxiety and performance was found during the transfer phase. In the first third of the transfer phase (Blocks 31 to 40) significant correlations were found between anxiety measures and 1 reaction time block; in the middle of the transfer phase (Blocks 41 to 50) significant correlations were found between anxiety measures and 7 reaction time blocks; and in the last third of the transfer phase (Blocks 51 to 60) significant correlations were found between anxiety measures and 8 reaction time blocks. The significant correlations between anxiety measures and the performance of older adults during transfer are presented in Table 14.

Paired-samples t-tests found that within both the young age group and the older age group, STAI-2 scores did not differ significantly from STAI-1 scores. However, an independent-samples t-test determined that the mean STAI-2 score for young participants ($M = 17.52$) was significantly higher than the mean STAI-2 score for older participants ($M = 14.77$), $t\ (87) = 2.589, p = .001$. Similarly, the mean Trait Anxiety score for young participants ($M = 38.67$) was significantly higher than the mean Trait Anxiety score for older participants ($M = 31.98$), $t\ (87) = 3.609, p = .001$.

Age group differences: Relationship between Anxiety and Working Memory

For the young age group, a significant correlation was found between the Trait Anxiety measure and working memory measures. Scores for Trait Anxiety correlated negatively with scores for Digits Backward Span ($r = -.374, p = .011$) and

Table 13.

Significant Correlations Between Measures Of Anxiety and Mean Block Reaction Times for Older Participants During the Training Phase.

	Anxiety Measures		
Block Number	STAI-1	STAI-2	Trait
	Older Participants (n = 43)		
4	.35*	.18	.33*
5	.32*	.18	.31*
6	.47**	.29	.33*
7	.32*	.18	.20
8	.43**	.25	.34*
9	.43**	.27	.26
10	.40**	.25	.26
11	.36*	.20	.21
12	.40**	.23	.25
14	.42**	.41**	.44**
16	.36*	.16	.20
17	.31*	.17	.20
18	.43**	.24	.33*
19	.32*	.22	.21
21	.37*	.08	.22
22	.42**	.27	.31*
23	.56**	.33*	.34*
24	.53**	.45**	.41**
25	.30*	.27	.33*
26	.56**	.35*	.34*
27	.41**	.32*	.27
28	.50**	.32*	.36*
29	.41**	.38*	.34*
30	.51**	.32*	.36*

*$p < .05$ **$p < .01$.

Table 14.

Significant Correlations Between Measures Of Anxiety and Mean Block Reaction Times for Older Participants During the Transfer Phase.

	Anxiety Measures		
Block Number	STAI-1	STAI-2	Trait
	Older Participants (n = 43)		
40	.35*	.21	.27
43	.41**	.20	.28
44	.36*	.18	.18
45	.42**	.28	.34*
47	.30	.32*	.24
48	.36*	.22	.20
49	.41**	.30	.25
50	.44**	.42**	.31*
52	.38*	.34*	.27
54	.41*	.19	.14
55	.36*	.40**	.30*
56	.47**	.42**	.29
57	.42**	.36*	.39**
58	.27	.37*	.24
59	.35*	.26	.22
60	.52**	.30	.33*

*$p < .05$ **$p < .01$.

Reading Span ($r = -.331$, $p = .024$). Thus, the greater the anxiety, the smaller the working memory capacity. In contrast, there were no significant correlations found between anxiety and working memory measures for the older age group. To determine whether the lack of correlations in the older age group may be due to this group having lower levels of variance in their anxiety scores, the standard deviations of anxiety scores were compared for each age group. Table 15 shows the standard deviations of measures of anxiety for young and older participants. It is clear from this table that the older age group had lower standard deviations compared to the younger age group, for all three anxiety measures.

Age group differences: Accuracy

For the young participants, there were no significant correlations between accuracy during training or transfer, and measures of anxiety. In contrast, for the older participants, accuracy during training correlated significantly with the STAI-1 ($r = -.497$, $p = .001$), with the STAI-2 ($r = -.362$, $p = .017$) and with Trait Anxiety ($r = -.340$, $p = .026$). Thus, the greater the anxiety of older individuals, the lower their accuracy levels during the training phase of the mental arithmetic task. However, accuracy during transfer did not correlate significantly with any measures of anxiety.

Correlations were also calculated between accuracy and measures of working memory for both age groups. The analysis for the young age group revealed a significant correlation between accuracy during transfer and the Digits Backward measure, $r = .331$, $p = .024$, such that the larger the working memory span of individuals, the higher their accuracy during the transfer phase of the mental

Table 15.

Standard Deviations of Anxiety Scores for Young and Older Participants.

	Anxiety Measures		
	STAI-1	STAI-2	Trait
Standard Deviations For Young Participants	5.34	5.29	9.93
Standard Deviations For Older Participants	5.17	4.70	7.28

arithmetic task. On the other hand, the analysis for the older age group revealed no significant correlations between accuracy and measures of working memory.

Paired-samples t-tests showed that accuracy within the young group decreased significantly in the transfer phase ($M = 90.5\%$) compared to the training phase ($M = 92.8\%$), $t\,(45) = 2.317$, $p = .025$. However, this trend was not found within the older group. Independent-samples t-tests revealed no significant difference in total accuracy between the young and the older participants.

Discussion

One of the aims of this experiment was to determine whether age differences existed in the acquisition and transfer of a mental arithmetic task. In particular, we investigated whether older adults engaged in general and/or specific learning for this task, and to what extent they relied on each type of learning. Another aim was to determine whether age differences in the acquisition and transfer of mental arithmetic were related to age differences in working memory functioning and anxiety.

In terms of learning, both young and older adults became significantly faster during both the training and transfer phases of the arithmetic task. In fact, a significant effect of practice was found for both age groups in both phases of the task. For both young and older adults, the graph of reaction time against practice resembled a power function, with performance becoming faster and more efficient with increasing practice. These results indicate that both age groups were able to learn a complex arithmetic task. However, there was a significant main effect of age on reaction time for both the training and transfer phases of the task. This suggests that the younger adults were consistently and significantly faster in performing mental arithmetic compared to the older adults. This slower response time of older adults has been attributed to declines in speed of information processing that occur with age (Cerella, 1985). These results support our hypotheses and replicate the findings from previous studies on aging and cognitive skill acquisition (e.g., Brigman & Cherry, 2002; Charness & Campbell, 1988; Salthouse & Coon, 1994; Salthouse & Kersten, 1993; Touron et al., 2001).

Moreover, the benefits of practice on reaction time were found to be the same for young and older adults in the training phase, but greater for the younger adults in the transfer phase of the arithmetic task. This implies that the repetition of problems over many trials allows participants to learn the task more efficiently, although it seems to benefit young adults more than older adults. The learning rates of young and older adults during training and transfer were also obtained by looking at the parameters of the power functions. This revealed that the learning rate for young adults was faster than the learning rate for older adults, during both phases of the arithmetic task. This replicates the results of Touron et al. (2001). Interestingly, the learning rate for young adults actually improved during transfer compared to training, whereas the learning rate for older adults declined during transfer. Also, the amount of improvement in reaction time for young and older adults was the same in both phases of the task. This result contradicts the findings of Touron et al. (2001), where the improvement span of young adults was found to be greater than of older adults. One possible explanation for this discrepancy is that older adults may have found the alphabet arithmetic task from Touron et al. (2001) more difficult compared to the arithmetic task in the present study, thus affecting the amount of improvement achieved. Finally, the level of accuracy for young and older adults was equal in both phases of the experiment, which corroborates the findings of other studies in this area (e.g., Brigman & Cherry, 2002; Touron et al., 2001; Salthouse & Coon, 1994).

A major hypothesis tested in this experiment was that both age groups would be able to partially transfer mental arithmetic skill. That is, it was predicted that during the arithmetic task, both age groups would be impaired initially in the transfer phase, but their reaction times would not return to pre-training levels. Such a result would indicate that both age groups engaged in a combination of specific and general learning during training. However, the results from this study indicated that the performance of young adults was so impaired at the start of transfer that their reaction times actually returned to pre-training levels. This suggests that no positive transfer occurred for the young age group, and that they relied entirely on specific learning during training. However, this issue was investigated further by extrapolating the training phase function of young adults into the transfer phase. This allowed the performance of young adults during the transfer phase to be compared to the performance predicted by their training phase function. By using this technique, it was found that the reaction times of young adults during transfer eventually fell within the 95% confidence intervals of their extrapolated training function by Block 45. Such a result suggests that some positive transfer did occur from the training phase to the transfer phase, and that young adults engaged in both specific and general learning during training. This finding of partial transfer for the young adults supports our hypothesis and substantiates the results of several other studies (e.g., Greig & Speelman, 1999; Knowlton & Squire, 1996).

For the older adults, their performance in the mental arithmetic task was also impaired at the start of transfer, but not enough to return to pre-training levels. This implies that some positive transfer did occur for the older age group and that they engaged in general as well as specific learning during training. Furthermore, when the learning curve for older adults during training was extrapolated to predict their performance during transfer, their reaction times fell within the 95% confidence intervals of the extrapolated training curve by Block 47 of the transfer phase. This result further suggests that older adults were able to retain and use the general skills learned during training. Taken together, these results indicate that older adults engaged in a combination of general and specific learning during training. Again, this finding supports our hypothesis and is consistent with other skill acquisition studies (e.g., Charness & Campbell, 1988; Touron et al., 2001). Therefore, both young and older adults demonstrated partial positive transfer in mental arithmetic, although probably to varying extents.

In terms of skill acquisition theories, the fact that both age groups were severely impaired at transfer suggests that some of their learning was specific to the training task, which supports Logan's Instance theory (Logan, 1988, 1990). However, Logan's Instance theory is not fully supported, because some positive transfer also occurred despite the use of new stimuli in the transfer task. The fact that older adults did not return to pre-training levels in the transfer phase, and that the performance of both age groups eventually fell within the confidence intervals of their extrapolated training functions, indicates that some general skills from training were retained and used during transfer. Thus, both age groups engaged in a combination of item-specific and item-general learning during training, which can be better explained by Anderson's ACT* theory (1982). That is, participants probably used item-general productions to perform the mental arithmetic task in the initial stages of training. Then, with practice, participants developed item-specific productions that were specific for certain problems. However, these item-specific productions could not be used in the transfer phase, since the task involved a new set of problems. Therefore, the performance of participants became slower in the initial stages of transfer. Nevertheless, participants were still able to use item-general productions developed during training in order to perform the task at transfer, which explains why their performance eventually returned to those levels predicted by their training phase performance.

Although both age groups seemed to learn a combination of general and specific skills during training, their different performances at transfer suggest that they learned these skills to varying degrees. For example, the finding that older adults experienced a significantly smaller decline in reaction time from Block 30 to Block 31 compared to the younger adults suggests that the amount of positive transfer was greater for older adults than for younger adults in the transfer phase, and that older adults relied more on general learning during training whereas younger adults relied more on specific learning. It is possible that older adults had more extensive training in mental arithmetic during their primary school education than younger adults, and that this accumulated experience affected their transfer of general learning. However, the younger adults were faster to return to their original learning curve during the transfer phase than the older adults (i.e., the transfer performance of younger adults fell within the confidence intervals of the extrapolated training function by Block 45, whereas the transfer performance of older adults did this by Block 47). This suggests that the amount of positive transfer was greater for the younger adults than for older adults in the transfer phase, and that the younger adults probably relied more on general learning during training while the older adults relied more on specific learning. Since these results directly contradict each other, it is difficult to determine the degree to which each age group engaged in each type of learning. Furthermore, these findings come from an artificial computer task rather than a life-like task, and do not necessarily reflect the amount of positive transfer that would be experienced by young and older adults in the real world. Therefore, the results have limited practical significance.

The present experiment also investigated the impact of working memory on the performance of participants. The three measures of working memory that were used in this experiment were the Digits Forward span, the Digits Backward span, and the Reading span. While the Digits Forward and Digits Backward measures correlated positively with each other for both age groups, the Reading Span measure did not correlate with the Digits Backward measure for the older age group. This suggests that Digits Forward and Digits Backward spans may measure similar aspects of working memory, whereas Reading span may measure a different aspect of working memory.

One of the issues investigated in this experiment was whether a relationship existed between working memory and the performance of participants, in terms of accuracy and reaction times. It was predicted that measures of working memory would correlate positively with the accuracy levels of each age group during both the learning and transfer phases of the mental arithmetic task. This hypothesis was not fully supported. For the young age group, no significant correlation was found between accuracy during training and working memory. However, a significant positive correlation was found between accuracy during transfer and the Digits Backward measure (which measures the functional capacity of working memory). This implies that the higher the working memory spans of participants (and the better the functioning of their working memory), the higher their accuracy levels during mental arithmetic, and vice versa. On the other hand, the analysis for the older age group revealed no significant correlations between accuracy and working memory. This suggests that individual differences in working memory span and functioning did not have an impact on the accuracy levels of older adults.

Correlations were also calculated between measures of working memory and mean reaction times for each age group during skill acquisition. It was predicted that measures of working memory for both age groups would correlate negatively with reaction times during both phases of the mental arithmetic task. For the young age group, no association was found between working memory span and reaction times during the training phase. However, significant negative correlations were found between working memory span and reaction times during the transfer phase, such that participants with high working memory spans demonstrated lower (i.e., faster) reaction times. Specifically, a small number of correlations were found in the first third of the transfer phase, and a high number of correlations were found during the middle and last third of the transfer phase. The correlations were mostly between the Digits Backward measure (which measures the functional capacity of working memory) and mean reaction times. The implication of these results is that for the young age group, individual differences in the functional capacity of working memory did not impact on the performance of mental arithmetic during training. This may be because all the participants in the young age group had sufficient working memory resources to process and store information during training. However, individual differences in the functional capacity of working memory seemed to have an effect during the transfer phase, such that young adults with larger working memory spans performed faster than those with smaller working memory spans. Moreover, the association between working memory span and performance seemed to become stronger by the middle and the end of the transfer phase. This could be because working memory was involved in the storing and retrieval of instances from long-term memory during the later stages of transfer (Brigman & Cherry, 2002). In contrast, the older age group showed no significant correlations between working memory span and mean reaction times during either the training or the transfer phase of the mental arithmetic task. Thus, individual differences in the functional capacity of working memory in older adults did not affect performance during mental arithmetic, suggesting that all the participants had sufficient working memory capacity and functioning to perform the task.

However, there may be alternative explanations for the lack of association between working memory span and reaction times for the older age group during training and transfer, and for the younger age group during training. For example, it may be that the task used in this experiment did not place enough demands on working memory, so that even participants with small working memory spans (i.e., with smaller storage capacity and less efficient processing) were able perform it without difficulty. Furthermore, the older adults in our sample were well educated, with 7 to 35 years of formal education (M = 12.2 years). This high level of education means that the older adults may have found the arithmetic problems too easy and not taxing enough for working memory involvement. Future experiments could increase the complexity of this task by using hierarchical problems instead of sequential problems, or using multiple digit problems instead of single digit problems, or asking participants to perform a secondary task (e.g., a memory load task) at the same time as the primary task. Such increases in task complexity may increase the involvement of working memory, which may result in a larger number of significant correlations with performance.

In terms of the working memory measures, it was hypothesized that young and older adults would perform equally well on the Digits Forward task, which measures the storage component of working memory (in particular, the phonological loop). The results supported this hypothesis, with the mean Digits Forward scores not differing significantly between the age groups. This implies that the phonological loop remains intact with age, which supports the conclusions of previous studies (e.g., Dolman et al., 2000; Jenkins et al., 2000; Phillips & Hamilton, 2001; Rouleau & Belleville, 1996; Tubi & Calev, 1989). On the other hand, it was predicted that mean scores for Digits Backward and Reading Span would be lower for older adults than for younger adults, because these tasks involve central executive functioning which is thought to deteriorate with age (Dobbs & Rule, 1989; Phillips, Gilhooly, Logie, Della Sala, & Wynn, 2001; Van der Linden, Bregart, & Beerten, 1994). While our analysis found that Digits Backward scores were indeed significantly lower for older adults than for younger adults, the Reading Span scores were not significantly different between the two age groups. Therefore, it is unclear from these results whether central executive functioning was impaired in our sample of older adults or not. Several researchers have actually proposed that central executive functioning can remain intact with age, because older adults can sometimes inhibit irrelevant information in tasks (a function of the central executive) as well as younger adults (e.g., Kramer, Humphrey, Larish, Logan, & Strayer, 1994; McDowd, 1997; Sullivan & Faust, 1993). To determine whether the older adults in our experiment retained their central executive functioning, their performance during the transfer phase of the mental arithmetic task was analysed.

It is feasible that a decline in central executive functioning in older adults would affect their amount of initial recovery during the transfer phase, compared to the younger age group. This is because initial recovery during transfer required algorithmic processing in order to solve new arithmetic problems. Since this processing places a load on central executive functioning, then the amount of initial recovery during transfer should be greater for younger adults than for older adults. However, this result was not obtained. In fact, the amount of initial recovery in the transfer phase was the same for both age groups. This suggests that the functioning of the central executive remained intact in our sample of older adults. However, it is also possible that the task did not place high enough demands on working memory, such that even older adults with impaired executive functioning were capable of performing this task. The fact that working memory did not correlate significantly with initial performance during transfer (Block 31 and Block 32) for either age group supports the theory that the task was not loading heavily on working memory, so that even participants with small working memory spans were able to solve the problems without difficulty.

However, it is also conceivable that central executive functioning in participants would affect the speed of their recovery in the transfer phase. This is because recovery in the transfer phase requires participants to use computational algorithms (that involve central executive processing) in order to solve new arithmetic problems. Since older adults are thought to have impaired central executive functioning, the speed of recovery in the transfer phase should be slower for older adults than for younger adults. That is, older adults should take longer to return to their Block 30 reaction times in the transfer phase, compared to younger adults. The results did not show this, however, with both age groups returning to their Block 30 reaction times by Block 48 of the transfer phase. This finding further supports the possibility that central executive functioning can remain intact with age.

However, it is again probable that the task did not place high enough demands on working memory, so that even older adults with impaired executive functioning were capable of performing it. This lack of loading on working memory would explain why no significant correlations were found for the older age group between working memory functioning and reaction times during the transfer phase. In contrast, the reaction times for the young age group were significantly correlated to working memory span during the transfer phase, such that differences in working memory functioning (including central executive functioning) were related to differences in reaction times. However, the differences in working memory functioning in young participants may have also been caused by differences in anxiety levels. The effect of anxiety on performance is discussed in the next section.

To determine the impact of anxiety on the performance of participants, the State-Trait Anxiety Inventory (Spielberger et al., 1983) was administered to all participants. A short version of the state anxiety questionnaire (STAI-1) and the full trait anxiety questionnaire were administered before the start of the computer task, and a second version of the state anxiety questionnaire (STAI-2) was administered after the training phase of the computer task. All three measures of anxiety correlated significantly with each other for both age groups. This suggests that all three questionnaires were measuring the same general construct of anxiety.

It was hypothesized that measures of state or trait anxiety would correlate negatively with reaction times and accuracy during the mental arithmetic task. This hypothesis was partially supported. For the young age group, significant correlations were found between state anxiety and reaction time during the training phase of the task, such that higher levels of anxiety were associated with slower reaction times. There were a larger number of significant correlations in the last third of the training phase, suggesting that the impact of state anxiety became stronger as the training phase progressed. On the other hand, anxiety had a lesser impact on performance during the transfer phase of the task. Significant correlations with state and trait anxiety were found mainly in the middle third of the transfer phase, suggesting that the negative effect of anxiety on reaction times became stronger as the transfer phase progressed, but declined again towards the end of transfer. However, no significant correlations were found between measures of anxiety and accuracy in either phase of the arithmetic task for the young age group. This implies that the anxiety levels of young adults did not have a detrimental effect on their accuracy levels during mental arithmetic.

For the older age group, significant correlations were found between state anxiety and reaction time during the training phase of the arithmetic task, such that higher levels of anxiety were related to slower reaction times. There were a larger number of significant correlations in the last third of the training phase, suggesting that the impact of state anxiety on performance increased as the training phase progressed. While anxiety had a lesser impact on performance during the transfer phase of the task, many significant correlations were still found between state anxiety and the middle and last third of the transfer phase. This implies that the negative effect of anxiety on reaction time increased as the transfer phase progressed. Furthermore, significant correlations were found between state anxiety, trait anxiety and accuracy in the training phase of the task, such that higher levels of anxiety were associated with lower levels of accuracy. Thus, anxiety did have a negative effect on the reaction times and accuracy of older adults, and on the reaction times of younger adults.

It was also predicted that measures of anxiety would correlate negatively with measures of working memory. Analysis for the young age group revealed significant negative correlations between trait anxiety and two measures of working memory (Digits Backward and Reading Span), such that high levels of trait anxiety in young adults were associated with smaller working memory spans. This supports the claims from several studies that anxiety interferes with working memory functioning (e.g., Ashcraft & Kirk, 2001; Hopko et al., 1998; Idzikowski & Baddeley, 1983a; Idzikowksi & Baddeley, 1987; Moldawsky & Moldawsky, 1952; Mueller, 1980). This impact of anxiety on working memory may explain why significant correlations were found between the working memory spans of young adults and their reaction times during the transfer phase of the arithmetic task (a finding that was discussed earlier). Indeed, it is feasible that as anxiety levels increased during the transfer phase, this caused impairments in working memory functioning, such that young adults with larger working memory capacities (and more efficient processing) were better able to cope with the task than those with smaller working memory capacities (and less efficient processing). The fact that significant correlations were found between state/trait anxiety and reaction times for young adults during the transfer phase gives weight to this theory. On the other hand, analysis for the older age group revealed no significant correlations between anxiety and working memory spans. Therefore, anxiety did not seem to interfere with working memory functioning in older adults. However, another explanation is that older adults had consistently lower levels of variance in their anxiety scores compared to younger adults. That is, the anxiety scores for the older age group had smaller standard deviations than those of the younger age group, and this may have affected the likelihood of obtaining significant correlations with working memory measures for this age group.

The final hypothesis was that older adults would display the same levels of state anxiety as younger adults, and equal or lower levels of trait anxiety than younger adults. This hypothesis was generally supported. While the STAI-1 scores for both young and older adults were the same, the STAI-2 scores for older adults were lower than for younger adults. Similarly, the trait anxiety of older adults was lower than that of younger adults. The lower levels of state and trait anxiety in older adults may be attributed to older adults becoming more psychologically stable with age, and better able to cope with stressful situations compared to younger adults. This has been found in numerous studies (e.g., Coolidge et al., 2000; Nakazato & Shimonaka, 1989).

In summary, both the young and older adults were able to learn a complex mental arithmetic task. While the older age group was consistently slower than the younger age group in performing the task, they were able to achieve the same level of accuracy as the younger age group. Both young and older adults also engaged in a combination of general and specific learning for this task, although probably to different extents. Furthermore, individual differences in working memory span appeared to have no effect on the performance of older adults, and no effect on the training performance of younger adults, which implies that differences in skill acquisition cannot be predicted by differences in working memory functioning. However, it is possible that the lack of association between working memory and performance occurred because the task was not placing enough demands on working memory. On the other hand, different levels of anxiety did seem to affect the reaction times and accuracy of older adults, and the reaction times of younger adults in the mental arithmetic task. Furthermore, higher levels of anxiety were associated with poorer working memory functioning in younger adults, but not in older adults. Older adults also had lower levels of state/trait anxiety than younger adults in this experiment, which may have provided them with some benefits during skill acquisition. Therefore, it may be that differences in skill acquisition are related to differences in the anxiety levels of participants.

The results of this experiment have great practical implications for society. The fact that both young and older adults learned a cognitive skill using a combination of general and specific learning suggests that both age groups can be taught these skills in a similar way. That is, older adults seem as capable of engaging in memory-based, item-specific learning as younger adults, although the two age groups probably do so to varying degrees. Thus, the results imply that instructors can teach cognitive skills to both age groups by using a combination of item-specific and item-general information.

Moreover, the present experiment tested the popular myth about aging that 'you can't teach an old dog new tricks'. In fact, the results from the experiment revealed that older adults were able to learn a complex cognitive task, they were able to become fast and efficient in the task, they improved as much as younger adults with practice, and they were as accurate as younger adults during the entire task. Furthermore, older adults were not as impaired initially as younger adults when their skills were transferred to another task, which suggests that they can adapt quickly to a new task. This ability to adjust quickly may be a benefit for older adults in the workplace, if they are transferred from one task to another that is the same in structure, but uses different items or information. However, it must be noted that the older adults in this experiment were volunteers from the community who seemed physically healthy (83.7% said they did not have health problems affecting performance) and mentally intact. Therefore, the results from this experiment suggest that aging does not necessarily bring about a decline in learning ability, and that older adults who stay physically and mentally healthy seem to have no difficulty in acquiring and transferring new skills.

Chapter 6: Experiment 2

A second experiment was conducted in order to investigate whether age differences in the acquisition and transfer of skill could be related to age differences in working memory functioning and anxiety. This experiment followed the same rationale, design and methodology as Experiment 1. The only change was that participants were given a cognitive/perceptual skill to learn (visual numerosity) rather than a cognitive skill (mental arithmetic). Visual numerosity is a task whereby participants must determine the number of items present in visual displays. This skill can be described as a perceptual skill because it relies heavily on visual perception in order to learn and perform it.

From the literature review presented in Chapter 4, it seems that both young and older adults are able to learn visual numerosity skill, as their response times become faster with practice. However, older adults are usually slower at performing this task and can have different accuracy levels compared to younger adults (Basak & Verhaeghen, 2003; Sliwinski, 1997). The research on learning rates in Jenkins and Hoyer (2000) also suggests that while older adults can count at the same rate as younger adults, they take longer to switch from algorithmic performance to memory-based performance compared to younger adults (i.e., older adults have slower learning rates).

When young adults are required to transfer visual numerosity skill from one task to another, where the second task has the same structure as the first but different stimuli (i.e., different visual displays are used), their performance becomes significantly impaired (Green, 1997; Lassaline & Logan, 1993; Logan, 1998). In fact, the performance of both young and older adults declines to the same degree at the beginning of transfer (Jenkins & Hoyer, 2000). This implies that both age groups are relying on the retrieval of instances from memory by the end of training, but are no longer able to use instances during the transfer phase when new visual displays are presented. That is, both age groups seem to rely on item-specific learning to the same extent during training (Logan, 1988). However, this does not mean that participants do not learn some general skills during training as well. For example, Anderson's ACT* Theory (1982) proposes that individuals may initially count items on the screen by using a series of item-general productions (e.g., a production for marking items, for mapping numbers onto items, for finding the numerosity of items). With practice, these multiple productions are compiled into single productions that are efficient, specific, and faster. During the transfer phase, however, the item-specific productions developed during training are no longer appropriate, which can explain why performance is slower in the initial stages of the transfer phase compared to the end stages of the training phase. However, individuals can still use the item-general productions developed during training, which can prevent their performance from returning to pre-training levels.

In terms of the Baddeley and Hitch model of working memory (1974), all three components of working memory (i.e., the phonological loop, the visuo-spatial sketchpad, and the central executive) seem to be heavily involved in performing visual numerosity. The phonological loop is involved in the initial stages of visual numerosity tasks, because the individual must have knowledge of the counting sequence, and must keep track of the running total (Baddeley & Logie, 1999; Buchner, Steffens, Irmen, & Wender, 1998; Hitch, 1978; Logie & Baddeley, 1987; Nairne & Healy, 1983). Similarly, the central executive is involved in the initial stages of visual numerosity tasks, because it regulates the individual's attention and processing functions (Engle, Kane, & Tuholski, 1999; Tuholski, Engle, & Baylis, 2001). However, the visuo-spatial sketchpad may also become involved in the later stages of visual numerosity tasks, as visual patterns are repeated across trials. This is because individuals may start to process and encode the global form of visual patterns, and may eventually store these visual patterns with their associated numerosities as 'instances' in long-term memory (Green, 1997; Lassaline & Logan, 1993; Logan, 1998). The findings of several research studies suggest that the VSSP may have a role in the processing and encoding of these visual patterns (Chun & Jiang, 1998; Postma & DeHaan, 1996; Lagasse, 1993).

Since all three components of working memory seem to be involved in performing visual numerosity tasks, it is important to determine whether changes occur in these working components with age. From the literature search presented in Chapter 4, it seems that the phonological loop remains intact with age (e.g., Dolman, Roy, Dimeck, & Hall, 2000; Jenkins, Myerson, Joerding, & Hale, 2000; Phillips & Hamilton, 2001), the central executive deteriorates with age (e.g., Dobbs & Rule, 1989; Kramer & Atchley, 2000; Phillips, Gilhooly, Logie, Della Sala, & Wynn, 2001; Van der Linden, Bregart, & Beerten, 1994) and the visuo-spatial sketchpad deteriorates with age (e.g., Cerella, Poon, & Fozard, 1981; Chagnon & McKelvie, 1992; Dror & Kosslyn, 1994). This means that older adults may find it more difficult to process and store visual information in this task, compared to younger adults. However, research studies focussing on visual processing in the VSSP have found no age differences in the processing or storing of low-level visual-spatial information (Faubert, 2000; Faubert & Bellefeuille, 2002). Therefore, it may be that older adults will not be disadvantaged in this task if the visual displays are simple.

The anxiety levels of participants may also have an effect on their performance during a visual numerosity task, with higher levels of anxiety associated with slower reaction times and lower levels of accuracy in many tasks (e.g., Leon, 1989; MacLeod & Donnellan, 1993; Markham & Darke, 1991; Tohill & Holyoak, 2000). Furthermore, a high level of state or trait anxiety is likely to interfere with working memory functioning, which results in impaired performance during skill acquisition (Baddeley, 1998; Idzikowski & Baddeley, 1983b). Since the levels of trait and state anxiety are usually lower in older adults than younger adults during skill acquisition (Chiriboga & Dean, 1978; Coolidge, Segal, Hook, & Stewart, 2000; Costa, McCrae, & Arenberg, 1980; Nakazato & Shimonaka, 1989), the performance of younger adults in visual numerosity may be more affected by anxiety than that of older adults.

Overview of the Study

One of the purposes of the present experiment was to investigate the issue of age differences in the acquisition and transfer of visual numerosity skill. While this has been investigated before (e.g., Green, 1997; Jenkins & Hoyer, 2000; Lassaline & Logan, 1993; Logan, 1998), no study has ever looked at whether age differences in working memory and anxiety are related to age differences in the acquisition and transfer of visual numerosity. To explore this possibility, young and older adults were recruited for the study and asked to perform a visual numerosity task on a computer, based on the Jenkins and Hoyer (2000) task. Participants were presented with visual displays of 6 to 13 stars on a computer screen, and were required to determine whether the total number of stars in each display equalled an odd number or an even number. In the training session, the positions of the stars were determined from a small set of x-y grid coordinates. Each visual display was presented several times during the training phase. In the transfer phase, participants were asked to perform the same task, but the positions of stars were changed and determined from a different set of x-y grid coordinates. Since the same task was used in both phases, participants were able to use a general counting algorithm to determine the numerosity of displays during both learning and transfer. Therefore, according to Anderson's ACT* Theory (1982), *complete* positive transfer should occur from one phase to the next. However, participants could also learn the task by storing specific visual displays and their corresponding numerosities as 'instances' in their memory. If participants use this strategy, then the change of stimuli at transfer would cause impairments in performance, because the instances learned during training would not be applicable to the visual displays presented during transfer. Therefore, according to Logan's Instance theory (1988), *no* transfer should occur between the tasks in this case. On the other hand, participants could engage in both general and specific learning during training, such that their performance would be impaired at transfer, but would not return to pre-training levels (i.e., *partial* positive transfer could occur). Partial transfer would also be evident if the observed transfer performance of participants eventually fell within the 95% confidence intervals of their extrapolated training phase functions (Speelman & Kirsner, 2001). This would imply that the transfer performance of participants could eventually be predicted by their training phase performance, and that participants were able to retain and use some of the general skills that they learned during training.

To determine the working memory spans of young and older adults in this experiment, the same measures were used as in Experiment 1. That is, the 'Digits Forward' span task (Wechsler, 1997) was administered to measure the storage component of working memory, and the 'Reading Span' task (Daneman & Carpenter, 1980) and 'Digits Backward' task (Wechsler, 1997) were administered to measure the storage and processing components of working memory. These latter tasks were assumed to measure the 'functional capacity' of working memory, such that individuals with smaller working memory capacities were assumed to have less efficient processing and therefore fewer resources available for storage, compared to individuals with larger working memory capacities (Daneman & Merikle, 1996). To measure the anxiety of participants during this experiment, the State-Trait Anxiety Inventory (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983) was used and administered as in Experiment 1.

Based on the research cited in this chapter regarding aging, the acquisition and transfer of visual numerosity skill, working memory and anxiety, it was hypothesised that:

- Young and older adults will become significantly faster in their performance of visual numerosity, from the beginning to the end of each learning phase.
- The graphs of reaction time against practice for both age groups during each phase of the visual numerosity task will resemble power or exponential functions.
- Older adults will be consistently slower than younger adults when performing the visual numerosity task.
- The effect of practice on reaction times will be greater for young adults than for older adults, during each phase of the visual numerosity task.
- The learning rate (determined by the 'c' parameter of learning functions) will be faster for young adults than for older adults in each phase of the visual numerosity task.

- The amount of improvement (in reaction time) that occurs from the beginning to the end of each phase of the visual numerosity task will be greater for young adults than for older adults.
- Both young and older adults will demonstrate partial positive transfer in the visual numerosity task.
- Measures of working memory will correlate positively with accuracy and negatively with reaction time during both phases of the visual numerosity task. That is, higher working memory spans will be associated with higher levels of accuracy and lower reaction times during the visual numerosity task.
- Young and older adults will perform equally well on the Digits Forward task, because this task measures the storage component of working memory (in particular, the phonological loop), which presumably stays intact with age.
- Older adults will perform more poorly on the Reading Span task and the Digits Backwards task compared to younger adults. This is because these tasks involve central executive functioning, which is thought to deteriorate with age.
- Measures of state and/or trait anxiety will correlate negatively with the performance of individuals during both phases of the visual numerosity task. That is, the higher the state/trait anxiety, the poorer the performance in terms of reaction time and accuracy.
- Measures of state and/or trait anxiety will correlate negatively with measures of working memory. That is, the higher the state/trait anxiety, the lower the working memory spans of individuals.

- Measures of state anxiety will not be significantly different for young and older adults, but measures of trait anxiety will be significantly higher for young adults than for older adults.

As well as testing these hypotheses, the present experiment aims to clarify some of the issues that remain unresolved in the aging and skill acquisition literature. For example, past research has provided mixed results about the accuracy levels of older adults compared to younger adults in visual numerosity tasks, with older adults sometimes achieving lower levels of accuracy than younger adults (e.g., Sliwinski, 1997) and sometimes achieving higher levels of accuracy than younger adults (e.g., Basak & Verhaeghen, 2003). It is also unclear whether young and older adults demonstrate the same or different amounts of positive transfer during visual numerosity tasks. A difference in the amount of positive transfer for each age group would imply that young and older adults learn visual numerosity tasks differently, and perhaps rely on general and specific skills to varying extents. Furthermore, it is uncertain whether young and older adults recover in the same way during the transfer phase of visual numerosity tasks. For example, it may be that young and older adults differ in their amount of initial recovery in the transfer phase (i.e., the mean difference in reaction time between the first two practice blocks of transfer) and in their speed of recovery in the transfer phase (i.e., how long it takes for participants to return to their final training phase reaction time during the transfer phase). It is likely that working memory functioning plays a vital role in the initial stages of the transfer phase, since participants need to revert to using general counting algorithms in order to determine the numerosities of new visual displays. Therefore, age differences in the amount of initial recovery and speed of recovery may be related to age differences in working memory functioning. However, anxiety may also be a factor contributing to the recovery performance of young and older adults during the transfer stage. It is hoped that the results of Experiment 2 will provide valuable information on these issues.

Method

Research Design

This experiment had exactly the same design as Experiment 1. Only the computer task was different.

Participants

This experiment used a convenience sample of 48 young and 48 older participants. The young participants were undergraduate students from Edith Cowan University, recruited through advertising on university notice boards. The older participants were recruited by advertising in community newspapers, retirement villages, nursing homes and senior citizen centers. Some older volunteers were also recruited through an organization called the Council on the Ageing (COTA). The data from one older participant was discarded because he failed to reach the learning criterion. As in the previous experiment, the learning criterion was defined as an accuracy rate of at least 70% in each of the training and transfer phases. This cut-off point separated those participants who understood the task from those who did not. The exclusion of this participant left 48 young participants and 47 older participants.

Of the 48 young participants, 9 were male and 39 were female. They were aged between 17 and 25 years ($M = 20.29$ years) and had 10 to 20 years of formal education ($M = 13.9$ years). Furthermore, 97.9% of these participants were native

English speakers, 95.8% denied taking medications causing drowsiness, and 93.8% denied having health problems affecting performance. The participants were randomly assigned to one of two experimental groups to enable the counterbalancing of stimulus items in the two phases of the experiment. Each group contained 24 participants.

Of the 47 older participants, 11 were male and 36 were female. They were aged between 65 and 89 years (M = 73.94 years) and had 6 to 18 years of formal education (M = 10.9 years). A high percentage (91.5%) of the participants were native English speakers, 93.6% denied taking medications causing drowsiness, and 89.4% denied having health problems affecting performance. Information about their past occupations is summarized in Table O1 (Appendix O). The number of years since they retired from full-time work ranged from 4 to 58 years (M = 17.75 years). The participants were randomly assigned to one of two experimental groups to enable the counterbalancing of stimulus items in the two phases of the visual numerosity task. Group one contained 24 participants and group two contained 23 participants.

Apparatus/Materials

As in Experiment 1, a number of self-report measures were used in this experiment. To measure the state and trait anxiety of individual participants, the STAI (Spielberger et al., 1983) was administered in each testing session. Again, the State Anxiety component of this tool was divided into two 10-item questionnaires (See Appendix B) while the Trait Anxiety component remained unaltered (see Appendix C).

To assess working memory, the Digit Span Task in the Wechsler Adult Intelligence Scale – 3rd Edition (Wechsler, 1997) was administered to each participant (see Appendixes E and F). The Reading Span task (Daneman & Carpenter, 1980) was then used to measure working memory capacity and processing (see Appendixes G and H).

The main skill acquisition task of this experiment was a visual numerosity task, adapted from Jenkins and Hoyer (2000). The instructions, task, and feedback were presented on four Apple Macintosh G3 computers with 17-inch monitors and standard keyboards (See Appendix P for instructions). Each computer was located in an individual soundproof room. The stimulus items were constructed using a 25 x 25 square grid with the computer program CorelDraw. A 12-sided die was used to obtain random *x*- and *y*-axis values for the stimuli on the grid. For example, if the die landed on '10' in the first throw, '6' on the second throw, '5' on the third throw, '12' on the fourth throw and so on, then the *x*-*y* coordinates would be (10, 6), then (5, 12) and so on, until enough coordinates were obtained for each numerosity level (i.e., 6 to 13 *x*-*y* coordinates). The final picture files for the stimuli did not show the grid; only the asterisks ('stars') were displayed. An example of the stimulus picture file used is given in Figure 6.

To perform the visual numerosity task, participants were required to count the number of stars that appeared on the screen. SuperLab Pro Version 1.74 was used to present the stimuli to the participants and to record their keyboard responses. Participants were asked to respond using a standard keyboard with the 'Z' key labelled 'O' for 'odd' and the '/' key labelled 'E' for 'even'. They were instructed to press 'O' if the total number of stars was an odd number, and to press 'E' if the total number of stars was an even number. The instructions emphasised the importance of

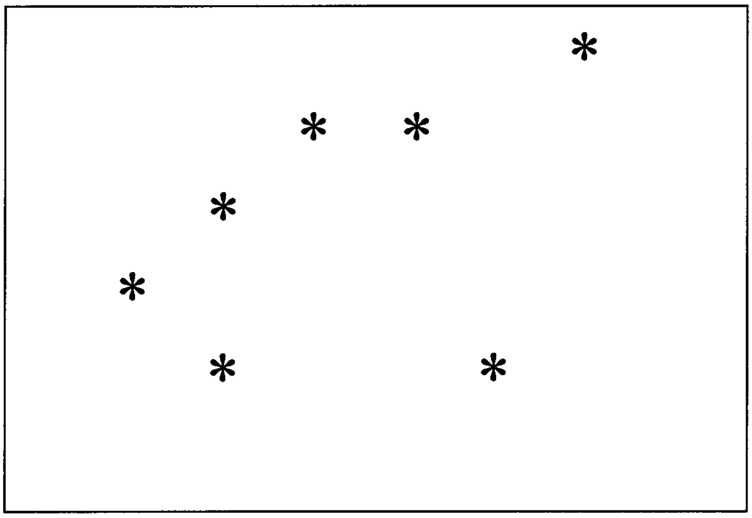

Figure 6. Example of a visual numerosity stimulus item displayed on the computer screen.

responding with speed as well as accuracy.

The participants were then given eight practice trials of the task, during which they were presented with pictures of 6 to 13 stars in random order. These practice trials had grid positions of stars that were not used in the actual experiment (see Table Q1 in Appendix Q for *x-y* coordinates of practice trials). Each practice trial was presented once only, and with the experimenter nearby in case the participant had any questions. When a participant responded on the keyboard, their response was always followed by feedback on the screen about whether they were correct or not. Participants were informed to 'press the space bar' in order to start the next trial.

For each of the training and transfer phases of the task, eight picture files with 6 to 13 stars were created as the stimulus items. The *x* and *y* grid coordinates used to create picture files in the training phase were different to those used to create picture files in the transfer phase (see Tables Q2 and Q3 in Appendix Q).

Procedure

Participants were tested in individual computer rooms. As in Experiment 1, they were asked to read and sign an informed consent form, they were administered a 10-item State Anxiety questionnaire (STAI-1 or STAI-2) followed by the Trait Anxiety questionnaire of the STAI (Spielberger et al., 1983), the Digit Span Task (Wechsler, 1997), and the Reading Span Task (Daneman & Carpenter, 1980).

Participants were then given the computer generated visual numerosity task, starting with eight practice trials. If participants were able to complete the practice trials, they continued with the training phase of the task. During the training phase, participants were presented with 30 blocks of eight trials (i.e., 240 trials). The *x-y* coordinates from either Set 1 or Set 2 (see Table Q2 and Table Q3, Appendix Q) were used to create the eight picture files (visual displays) presented in each block. The eight picture files covered every numerosity level (i.e., 6 to 13 stars) and were presented in a random order within each block.

After the training phase of the visual numerosity task, participants were asked to complete a second 10-item State Anxiety questionnaire (STAI-1 or STAI-2). This was done to assess changes in their state anxiety as the experiment progressed. The administration of the two 10-item versions of the State questionnaires was counterbalanced across participants, so that half of the participants were given the STAI-1 before doing the computer task and the STAI-2 later, while the other half were given the STAI-2 before doing the computer task and the STAI-1 later.

When the second STAI questionnaire was completed, participants were given a 5-minute break with tea or coffee before commencing the transfer phase of the visual numerosity task. During the transfer phase, participants were given another 30 blocks of eight trials. However, each of the 8 trials used picture files created from the *x* and *y* coordinates of the stimulus set not used during the training phase (see Tables Q2 and Q3). Thus, the picture files used in the transfer phase were different to those used in the training phase. Again, the eight picture files covered every numerosity level and were presented in a random order within each block.

In order to control for possible differences in the item difficulty of the two sets, the items presented in the training and transfer phases were counterbalanced for this experiment. That is, half of the participants in each age group were presented with Set 1 picture files during the training phase and Set 2 picture files during the transfer phase, while the other half of the participants in each age group were presented with the opposite order.

After participants completed the transfer phase of the computer task, they were asked to fill out a participant detail sheet to obtain demographic data (See Appendix K).

Results

The results of this experiment were analysed using Microsoft Excel 2000 and SPSS 11.0 software for Windows. Only the reaction times from correct trials were used for analysis. The mean reaction times and standard deviations of young participants from Block 1 to 30 (training) and Block 31 to 60 (transfer) are shown in Table R1 and Table R2 (see Appendix R). The mean reaction times and standard deviations of older participants from Block 1 to 30 (training) and Block 31 to 60 (transfer) are shown in Table S1 and Table S2 (see Appendix S). Mean reaction times for young and older participants are presented in Figure 7. All statistical tests performed on the data were two-tailed tests with $\alpha = 0.5$.

Young Participants: Practice and transfer effects

The average accuracy for young participants during the training phase was 94.6 %, whereas during the transfer phase it was 93.5 %. The mean reaction times and standard deviations for Block 1, Block 2 and Block 30 in the training phase; and Block 31, Block 32 and Block 60 in the transfer phase, are presented in Table 16.

A within-subjects repeated measures ANOVA demonstrated a significant reduction in response time from Block 1 to Block 2, $F(1,47) = 6.819, p < .05$; and from Block 1 to Block 30, $F(1,47) = 150.307, p < .05$. Similarly, response time decreased significantly in the transfer phase from Block 31 to Block 32, $F(1,47) = 13.311, p < .05$; and from Block 31 to Block 60, $F(1,47) = 125.193, p < .001$.

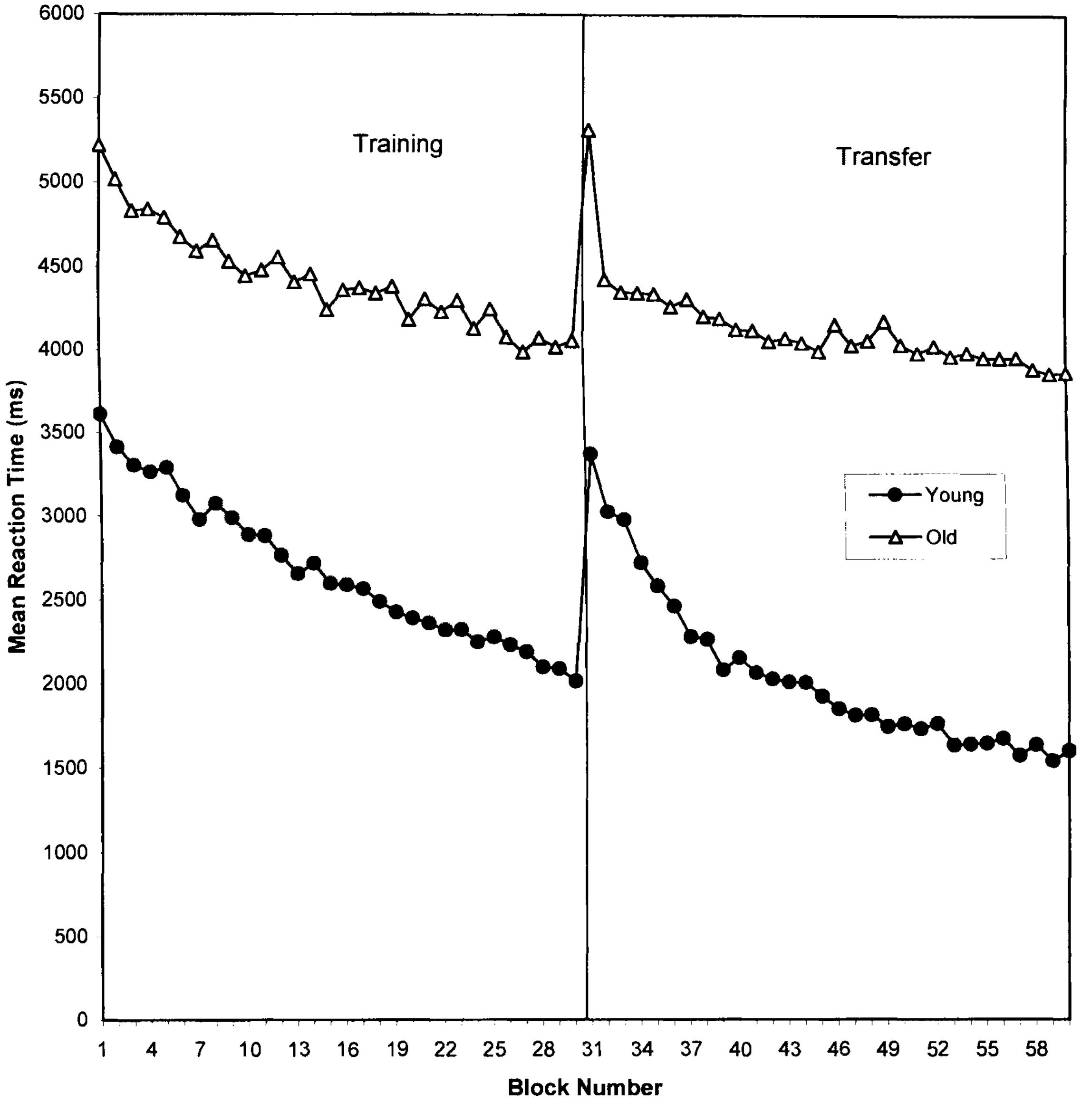

Figure 7. Mean reaction times (ms) for young and older participants during training and transfer.

Table 16.

Mean Reaction Times and Standard Deviations for Blocks in the Training Phase and the Transfer Phase for the Young Participants.

Block Number	Mean Reaction Time (ms)	Standard Deviation (ms)
Block 1	3611	845
Block 2	3414	788
Block 30	2008	704
Block 31	3365	895
Block 32	3017	719
Block 60	1590	783

Within-subjects repeated measures ANOVAs revealed a significant effect of practice in both the training phase, $F(1,29) = 43.990$, $p < .001$, and the transfer phase, $F(1,29) = 50.314$, $p < .001$.

Within-subjects repeated measures ANOVAs were used to determine whether transfer occurred from the training phase to the transfer phase. The response time for participants was significantly slower in Block 31 than in Block 30, $F(1,47) = 111.925$, $p < .001$, although response time in Block 31 was still significantly faster than in Block 1, $F(1, 47) = 6.605$, $p < .05$. This suggests that some positive transfer did occur from the training phase to the transfer phase.

A power function of the form $RT = a + bP^c$ (where 'RT' is reaction time, 'P' is the number of blocks of practice, and 'a', 'b' and 'c' are performance parameters) was fitted to the training data using Microsoft Excel. An exponential function of the form $RT = a + be^{cP}$ (where 'RT' is reaction time, 'P' is the number of blocks of practice, 'e' is the exponential base, and 'a', 'b' and 'c' are performance parameters) was also fitted to the training data, to determine if it was a better fit than the power function. The parameters of the fitted functions and two measures of goodness of fit (r^2 and *rmsd*, the root mean squared deviation between predicted and observed values) are presented in Table 17. An attempt was made initially to fit functions with non-zero asymptotes (i.e., 'a' values other than zero) to the data. However, functions with zero asymptotes always provided better fits to the training data. The higher r^2 value and lower *rmsd* value for the exponential curve (in Table 17) suggests that this function is the better fit for the training data. To determine whether performance in the transfer phase deviated significantly from that which was predicted by performance in the training phase, confidence intervals ($\alpha = .05$) were calculated for the transfer phase data. The observed reaction times for the training and transfer

Table 17.

Parameters and Measures of Goodness of Fit for the Power Function and Exponential Function Fitted to Mean Reaction Times of Young Participants for the Training Phase.

	Fitted parameters			Goodness of fit	
	a	*b*	*-c*	r^2	*rmsd*
Power function	0	4136.3	0.1814	.888	159.22
Exponential function	0	3506.7	0.0185	.986	54.07

phases, the exponential function for the training phase (extrapolated into the transfer phase), and the 95% confidence intervals for all the data, are shown in Figure 8. From this figure, it seems that the young participants did not return to their original learning curve in the transfer phase.

Older Participants: Practice and transfer effects

During the training phase, the average accuracy for older participants was 97.3 %, whereas during the transfer phase it was 97.0%. The mean reaction times and standard deviations for Block 1, Block 2 and Block 30 in the training phase; and Block 31, Block 32 and Block 60 in the transfer phase, are summarized in Table 18.

A within-subjects repeated measures ANOVA demonstrated a significant reduction in response time from Block 1 to Block 30, $F(1,46) = 44.573, p < .001$, but not from Block 1 to Block 2. In the transfer phase, response time decreased significantly from Block 31 to Block 32, $F(1,46) = 69.977, p < .001$; and from Block 31 to Block 60, $F(1,46) = 93.715, p < .001$. Within-subjects repeated measures ANOVAs revealed a significant effect of practice in both the training phase, $F(1,29) = 43.990, p < .001$, and the transfer phase, $F(1,29) = 50.314, p < .001$.

Within-subjects repeated measures ANOVAs were used to determine whether transfer occurred from the training phase to the transfer phase. The response time for participants was significantly slower in Block 31 than in Block 30, $F(1,46) = 82.146, p < .001$, so much so that response time at Block 31 did not differ significantly from response time at Block 1. This implies that no positive transfer occurred from the training phase to the transfer phase.

A power function of the form $RT = a + bP^c$ (where 'RT' is reaction time, 'P' is the number of blocks of practice, and 'a', 'b' and 'c' are performance parameters)

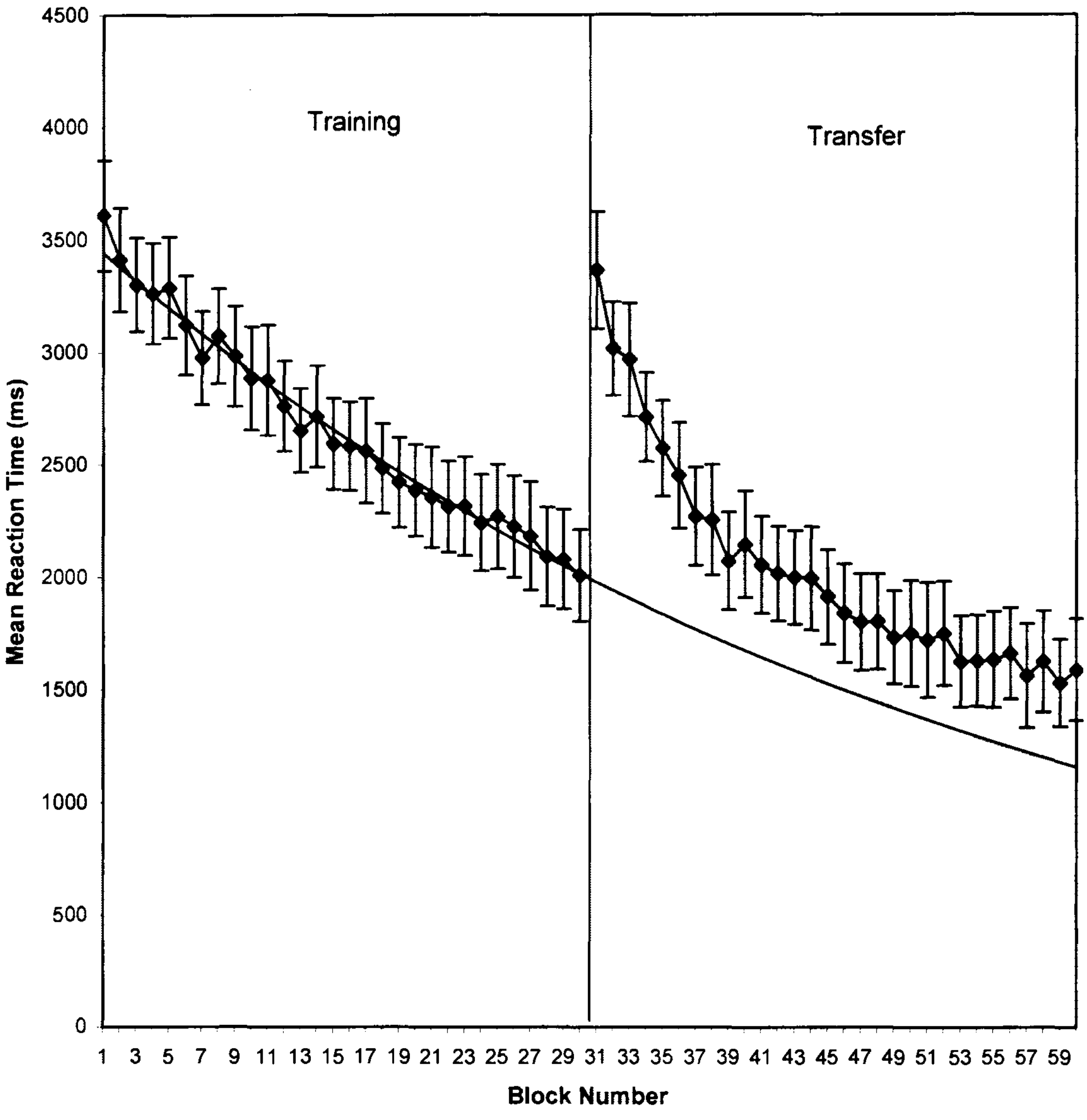

Figure 8. Observed reaction times for training and transfer with 95% confidence intervals, and fitted exponential function extrapolated to transfer phase, for young participants.

Table 18.

Mean Reaction Times and Standard Deviations for Blocks in the Training Phase and the Transfer Phase for the Older Participants.

Block Number	Mean Reaction Time (ms)	Standard Deviation (ms)
Block 1	5221	1399
Block 2	5016	1366
Block 30	4055	1105
Block 31	5316	1147
Block 32	4425	1019
Block 60	3858	1233

was fitted to the training data using Microsoft Excel. An exponential function of the form RT = a + be^{cP} (where 'RT' is reaction time, 'P' is the number of blocks of practice, 'e' is the exponential base, and 'a', 'b' and 'c' are performance parameters) was also fitted to the training data, to determine if this function was a better fit than the power function. The parameters of the fitted functions and two measures of goodness of fit (r^2 and *rmsd*, the root mean squared deviation between predicted and observed values) are presented in Table 19. Again, functions with zero asymptotes were found to provide better fits to the data than functions with non-zero asymptotes. The higher r^2 value and lower *rmsd* value for the power curve suggests that this function is the better fit for the training data. To determine whether performance in the transfer phase deviated significantly from that which was predicted by extrapolating from performance in the training phase, confidence intervals ($\alpha = .05$) were calculated for the transfer phase data. The observed reaction times for the training and transfer phases, the power function for the training phase (extrapolated into the transfer phase), and the 95% confidence intervals for all the data, are shown in Figure 9. From this figure, it seems that the older participants returned to their original learning curve by the third block of the transfer phase (i.e., Block 33).

Age group differences: Practice and transfer effects

A within-subjects repeated measures ANOVA found a significant main effect of age on reaction time, for both the training phase, $F(1,29) = 83.556, p < .001$, and the transfer phase, $F(1,29) = 127.05, p < .001$. This suggests that the young participants were consistently and significantly faster than older participants during both phases of the experiment. The analysis also found a block X age interaction in both the training phase, $F(1,29) = 2.28, p < .001$, and the transfer phase, $F(1,29) =$

Table 19.

Parameters and Measures of Goodness of Fit for the Power Function and Exponential Function Fitted to Mean Reaction Times of Older Participants for the Training Phase.

	Fitted parameters			Goodness of fit	
	a	*b*	*-c*	r^2	*rmsd*
Power function	0	5336.1	0.0760	.9239	79.28
Exponential function	0	4940.7	0.0072	.8973	97.79

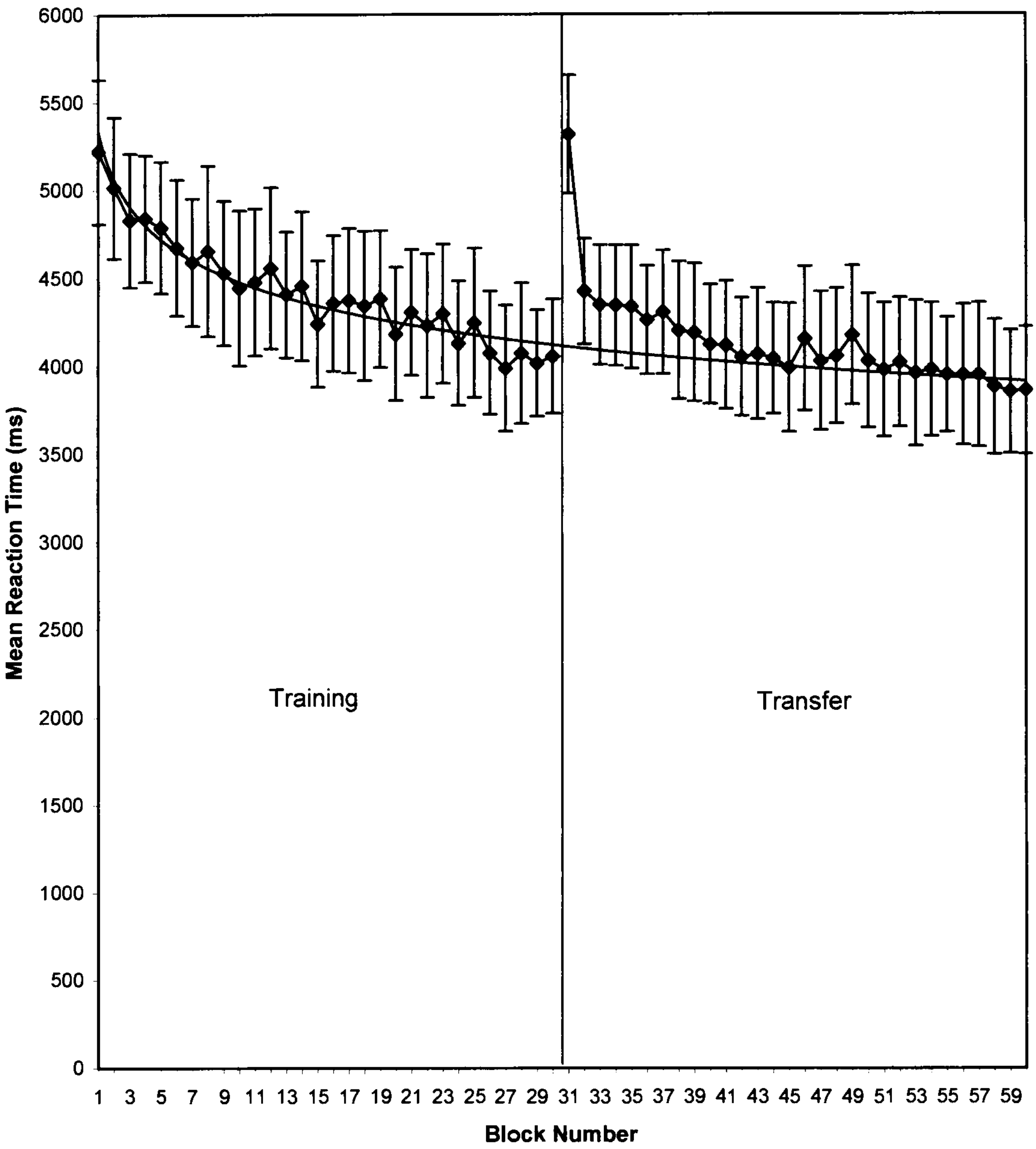

Figure 9. Observed reaction times for training and transfer with 95% confidence intervals, and fitted power function extrapolated to transfer phase, for older participants.

6.999, $p < .001$. These results, plus the learning curves presented in Figure 7, imply that the practice effect was greater for young participants than for older participants in both phases of the experiment. That is, the decrease in reaction time with each block of practice was greater for the young adults than for the older adults throughout the experiment.

The learning rates of young and older participants were obtained from the parameters of the learning curves of the two age groups. For the young age group, performance during the training phase was best described by an exponential function of the form $RT = a + be^{-cP}$ (where 'RT' is reaction time, 'P' is the number of blocks of practice, 'e' is the exponential base, and 'a', 'b' and 'c' are performance parameters) whereas for the older age group, performance was best described by a power function of the form $RT = a + bP^{-c}$ (where 'RT' is reaction time, 'P' is the number of blocks of practice, and 'a', 'b' and 'c' are performance parameters). The nature of the exponential function is such that it decreases more rapidly than the power function, and thus produces a steeper curve than the power function (Lane, 1987). Therefore, the learning rate for the younger adults was faster than that of the older adults during the training phase. To determine what the best-fitting functions were for the performance of young and older adults during the transfer phase, Microsoft Excel software was used. The parameters of these transfer phase functions and measures of goodness of fit (r^2 and *rmsd*, the root mean squared deviation between predicted and observed values) for young and older adults are presented in Table 20. For both age groups, power functions had higher r^2 values and lower *rmsd* values, which suggests that they provided better fits to the transfer data than exponential functions. Since the parameter 'c' in power functions represents the learning rate or the rate of change (Touron, Hoyer & Cerella, 2001), it is clear from

Table 20.

Parameters and Measures of Goodness of Fit for the Transfer Phase Functions of Young and Older Participants.

	Fitted parameters			Goodness of fit	
	a	*b*	*-c*	r^2	*rmsd*
	Young Participants (n = 48)				
Power function	0	3691.2	0.2485	.9778	83.36
Exponential function	0	2837.9	0.0229	.8927	167.98
	Older Participants (n = 47)				
Power function	0	4858.1	0.0659	.8429	111.32
Exponential function	0	4489.1	0.0055	.6260	172.69

Table 20 that the younger adults had a faster learning rate (c = -.2485) compared to older adults (c = -.0659) during the transfer phase.

The improvement span of each age group was also analysed. This refers to the amount of improvement in reaction time brought about by practice. To examine this, the difference in reaction time between Block 30 and Block 1 was found for each participant, as well as the difference in reaction time between Block 60 and Block 31. Independent samples t-tests were then used to compare the mean differences for each age group. The result was that the improvement span for young participants in the training phase was significantly greater than for older participants, t (93) = 2.013, p = .047. However, there was no significant difference in improvement span between age groups in the transfer phase.

To determine whether the amount of positive transfer differed significantly between the age groups, the difference in reaction time between Block 31 and Block 30 was found for each participant. An independent samples t-test established no significant difference between the mean differences of the two groups. Further analysis with a one-way repeated-measures ANOVA found a main effect of Block on transfer reaction times, F (1,93) = 191.694, p < .001, a main effect of Age on transfer reaction times, F (1.93) = 127.683, p < .001, but no significant Block X Age interaction. When an ANCOVA was performed however in which Block 30 reaction times were statistically controlled for, there was a significant effect of age on Block 31 reaction times, F (1,95) = 6.610, p < .012, such that older adults experienced a smaller decline in reaction time (from Block 30 to Block 31) compared to younger adults. However, the previous within-subjects results found that young adults did not return to their Block 1 reaction times during Block 31, whereas older adults did. This implies that although older adults experienced a smaller decline in reaction time (from Block 30 to Block 31) compared to younger adults, this decline was enough to return them to their Block 1 performance. Therefore, the amount of positive transfer for younger adults was actually greater than for older adults.

To determine whether the amount of initial recovery in the transfer phase differed significantly between age groups, the difference in reaction times between Block 32 and Block 31 was found for each participant. An independent samples t-test was used to compare the mean differences of the two groups. The t-test indicated that the amount of initial recovery for the young group (M = 348.46ms) was significantly less than the amount of initial recovery for the older group (M = 891.40ms), t (93) = 3.798, $p < .001$. There was no difference, however, between young and older participants in the rate of recovery in the transfer phase. Both young and older participants returned to their Block 30 reaction time by Block 42 of the transfer phase (see Figure 8 and Figure 9).

Age group differences: Working memory measures

The intercorrelations between working memory measures (WM) for young and old participants are displayed in Table 21.

To determine whether a relationship existed between working memory and performance (i.e., reaction time), correlations were performed between working memory measures and each block of performance during the training and transfer phases. For the young participants, working memory measures correlated with performance particularly during the middle of the training phase. In the first third of the training phase (Blocks 1 to 10), significant correlations were found between working memory and 2 reaction time blocks; in the middle third of the training phase (Blocks 11 to 20) significant correlations were found between working memory and

Table 21.

Intercorrelations Between Digits Forward (Digits F), Digits Backward (Digits B), Digit Span Total (Digit Span) and Reading Span, for Young and Old Participants.

WM Measures	Digits F	Digits B	Digit Span	Reading Span
		Young Participants (n = 48)		
Digits F		.48**	.86**	.23
Digits B			.85**	.13
Digit Span				.21
		Old Participants (n = 47)		
Digits F		.60**	.92**	.20
Digits B			.87**	.21
Digit Span				.23

**p < .01.

all 10 reaction time blocks; and in the last third of the training phase (Blocks 21 to 30) significant correlations were found between working memory and 7 reaction time blocks. The significant correlations between working memory measures and performance during training are presented in Table 22. For the young participants, working memory measures also correlated with performance during the transfer phase. In the first third of the transfer phase (Blocks 31 to 40) working memory measures did not correlate significantly with any reaction time blocks, but in the second third of the transfer phase (Blocks 41 to 50) working memory measures correlated significantly with 3 reaction time blocks, and in the last third of the transfer phase (Blocks 51 to 60) working memory measures correlated significantly with 7 reaction time blocks. The significant correlations between working memory measures and performance during transfer are presented in Table 23.

On the other hand, a smaller number of significant correlations were found between working memory measures and performance for the older adults. During the first third of the training phase (Blocks 1 to 10) no significant correlations were found between working memory and reaction time blocks; during the second third of the training phase (Blocks 11 to 20) significant correlations were found between working memory and 5 reaction time blocks; and during the last third of the training phase (Blocks 21 to 30) significant correlations were found between working memory and 2 reaction time blocks. The significant correlations for older adults between working memory measures and performance in the training phase are presented in Table 24. In contrast, no significant correlations were found for the older adults between working memory and performance during the transfer phase.

Independent-samples t-tests revealed that mean scores for the Digits Backward task were not significantly different between the two age groups.

Table 22.

Significant Correlations Between Measures Of Working Memory and Mean Block Reaction Times for Young Participants During Training.

	Working Memory Measures		
Block Number	Digits F	Digits B	Reading Span
	Young Participants (n = 48)		
9	-.26	-.29*	-.20
10	-.28*	-.17	-.28
11	-.29*	-.20	-.11
12	-.39**	-.25	-.14
13	-.40**	-.18	-.14
14	-.40**	-.11	-.10
15	-.41**	-.19	-.17
16	-.35*	-.14	-.12
17	-.45**	-.18	-.22
18	-.37*	-.19	-.15
19	-.41**	-.20	-.32*
20	-.39**	-.20	-.13
21	-.30*	-.10	-.19
22	-.30*	-.11	-.33*
23	-.26	-.10	-.32*
24	-.34*	-.17	-.31*
25	-.35*	-.19	-.28*
28	-.27	-.04	-.32*
29	-.24	-.13	-.31*

*$p < .05$ **$p < .01$.

Table 23.

Significant Correlations Between Measures Of Working Memory and Mean Block Reaction Times for Young Participants During Transfer.

	Working Memory Measures		
Block Number	Digits F	Digits B	Reading Span
	Young Participants (n = 48)		
41	-.22	-.30*	-.19
45	-.31*	-.19	-.17
48	-.28*	-.20	-.18
52	-.30*	-.20	-.20
53	-.32*	-.20	-.20
54	-.29*	-.20	-.13
57	-.28*	-.22	-.18
58	-.32*	-.21	-.27
59	-.32*	-.13	-.22
60	-.32*	-.21	-.30*

*$p < .05$ **$p < .01$.

Table 24.

Significant Correlations Between Measures Of Working Memory and Mean Block Reaction Times for Older Participants During Training.

	Working Memory Measures		
Block Number	Digits F	Digits B	Reading Span
	Older Participants (n = 47)		
11	-.16	-.29*	.27
13	-.20	-.33*	.02
14	-.17	-.29*	.13
17	-.21	-.32*	.12
20	-.27	-.31*	.09
24	-.25	-.36*	.18
27	-.12	-.31*	.22

*$p < .05$ **$p < .01$.

However, the mean score for Digits Forward in the young group (M = 11.46) was significantly higher than the mean score for the older group (M = 10.02), t (93) = 3.042, p = .003. Similarly, the mean score for Reading Span in the young group (M = 2.58) was significantly higher than the mean score for the older group (M = 2.28), p = .007. The mean scores and standard deviations of the working memory measures are found in Table T1 (Appendix T).

Age group differences: Anxiety measures

For both the young and older age groups, the two measures of State Anxiety (STAI-1 and STAI-2) correlated positively with each other, as well as with the Trait Anxiety measure (for the young group). For the older group, Trait Anxiety correlated with STAI-1 but not with STAI-2 (see Table 25).

To determine whether a relationship existed between anxiety and performance (i.e., reaction time), correlations were performed between anxiety measures and each block of performance during the training and transfer phases. For the young participants, anxiety measures correlated minimally with performance during the training phase. In the first third of the training phase (Blocks 1 to 10), anxiety scores correlated with only 1 reaction time block; in the second third of training (Blocks 11 to 20) anxiety scores correlated significantly with 2 reaction time blocks; and in the last third of training (Blocks 21 to 30) anxiety scores correlated significantly with 4 reaction time blocks. The significant correlations between anxiety measures and performance during training are presented in Table 26. Anxiety in young adults correlated with their performance to a greater extent during the transfer phase of the experiment. In the first third of the transfer phase (Blocks 31 to 40), significant correlations were found between anxiety measures and 1 reaction time block; in the

Table 25.

Intercorrelations Between Anxiety Measures for Young and Older Participants.

Anxiety Measures	STAI-1	STAI-2	Trait Anxiety
	Young Participants (n = 48)		
STAI-1		.48**	.40**
STAI-2			.56**
	Old Participants (n = 47)		
STAI-1		.40**	.22
STAI-2			.61**

** $p < .01$.

Table 26.

Significant Correlations Between Measures Of Anxiety and Mean Block Reaction Times for Young Participants During the Training Phase.

	Anxiety Measures		
Block Number	STAI-1	STAI-2	Trait
	Young Participants (n = 48)		
10	.06	.30*	.26
15	.10	.29*	.24
19	.13	.17	.32*
22	.14	.25	.35*
23	.11	.28*	.28
29	.15	.22	.34*
30	.12	.26	.32*

*$p < .05$ **$p < .01$.

second third of the transfer phase (Blocks 41 to 50) significant correlations were found between anxiety measures and 9 reaction time blocks; in the final third of the transfer phase (Blocks 51 to 60) significant correlations were found between anxiety measures and all 10 reaction time blocks. The significant correlations between anxiety measures and the performance of young adults during transfer are presented in Table 27.

The performance of older adults during each phase of the experiment was also associated with measures of anxiety, but to a smaller degree than for the young age group. In the first third of the training phase (Blocks 1 to 10), anxiety scores correlated significantly with 1 reaction time block; in the middle of the training phase (Blocks 11 to 20) anxiety correlated significantly with 2 reaction time blocks; and in the last third of the training phase (Blocks 21 to 30) anxiety correlated significantly with 3 reaction time blocks. The significant correlations between anxiety measures and the performance of older adults during training are presented in Table 28. On the other hand, no significant correlations were found between anxiety measures and reaction time in the first third of the transfer phase (Blocks 31 to 40); only 1 significant correlation was found between anxiety and reaction time in the second third of the transfer phase (Blocks 41 to 50), and only 1 significant correlation was found between anxiety and reaction time in the last third of the transfer phase (Blocks 51 to 60). The significant correlations between anxiety measures and the performance of older adults during transfer are presented in Table 29.

Paired-samples t-tests found that STAI-1 scores did not differ significantly from STAI-2 scores, both within the young group and within the old group. However, an independent-samples t-test determined that the mean STAI-2 score for young participants ($M = 16.83$) was significantly higher than the mean STAI-2 score

Table 27.

Significant Correlations Between Measures Of Anxiety and Mean Block Reaction Times for Young Participants During the Transfer Phase.

	Anxiety Measures		
Block Number	STAI-1	STAI-2	Trait
	Young Participants (n = 48)		
40	.04	.28	.30*
41	.12	.30*	.28
42	.07	.28*	.20
43	.08	.35*	.28
44	.16	.31*	.34*
45	.15	.25	.30*
47	.22	.34*	.32*
48	.21	.37**	.33*
49	.15	.37**	.34*
50	.14	.30*	.27*
51	.19	.34*	.21
52	.13	.29*	.23
53	.15	.34*	.30*
54	.14	.36*	.34*
55	.17	.36*	.30*
56	.14	.31*	.29*
57	.14	.30*	.27
58	.18	.34*	.34*
59	.13	.30*	.30*
60	.07	.29*	.28

*$p < .05$ **$p < .01$.

Table 28.

Significant Correlations Between Measures Of Anxiety and Mean Block Reaction Times for Older Participants During the Training Phase.

	Anxiety Measures		
Block Number	STAI-1	STAI-2	Trait
	Older Participants (n = 47)		
2	.12	.31*	-.03
13	.08	.29*	.04
18	.04	.29*	.06
22	.08	.30*	.07
23	.00	.29*	.12
30	.12	.30*	.12

*$p < .05$ **$p < .01$.

Table 29.

Significant Correlations Between Measures Of Anxiety and Mean Block Reaction Times for Older Participants During the Transfer Phase.

	Anxiety Measures		
Block Number	STAI-1	STAI-2	Trait
	Older Participants (n = 47)		
47	.30*	.03	.14
56	.30*	.17	.15

*$p < .05$ **$p < .01$.

for older participants ($M = 13.57$), $t\,(93) = 4.093$, $p < .001$. Similarly, the mean Trait Anxiety score for young participants ($M = 37.56$) was significantly higher than the mean Trait Anxiety score for older participants ($M = 33.38$), $t\,(93) = 2.419$, $p = .018$.

Age group differences: Relationship between Anxiety and Working Memory

For the young age group, a significant correlation was found between state anxiety and working memory: the STAI-2 correlated negatively with the Digits Backward task, $r = -.317$, $p = .028$. However, the Trait Anxiety measure did not correlate with any working memory measures.

For the older age group, no significant correlations were found between anxiety measures and working memory measures. To determine whether the lack of correlations in older adults may be due to this group having lower levels of variance in their anxiety scores, the standard deviations of anxiety scores were compared for each age group. Table 30 shows the standard deviations of measures of anxiety for young and older participants. It is clear from this table that the older age group had lower standard deviations than the younger age group for the STAI-2 and the Trait Anxiety measures.

Age group differences: Accuracy

For both age groups, there were no significant correlations between accuracy during training or transfer, and measures of anxiety. In contrast, significant correlations were found between accuracy and measures of working memory for both age groups. For the young participants, a significant correlation was found between accuracy in training and the Digits Backward measure ($r = .321$, $p = .026$) and accuracy in transfer and the Reading Span measure ($r = .384$, $p = .007$). For the older

Table 30.

Standard Deviations of Anxiety Scores for Young and Older Participants.

	Anxiety Measures		
	STAI-1	STAI-2	Trait
Standard Deviations For Young Participants	3.26	4.03	8.70
Standard Deviations For Older Participants	4.24	3.72	8.12

participants, a significant correlation was found between accuracy in training and the Reading Span task ($r = .378, p = .009$). Moreover, significant correlations were found between accuracy in transfer and the Digits Forward task ($r = .316, p = .030$) and accuracy in transfer and the Reading Span task ($r = .355, p = .014$).

Paired-samples t-tests found that accuracy for the young group was significantly lower in the transfer phase ($M = 93.5\%$) compared to the training phase ($M = 94.6\%$), $t\ (47) = 2.102, p = .041$. However, this trend was not found for the older group.

An independent-samples t-test was conducted to determine whether a significant difference existed in mean total accuracy between young and older participants. The test established that mean total accuracy for young participants ($M = 94.08\%$) was significantly lower than that for older participants ($M = 97.14\%$), $t\ (93) = 3.367, p = .001$.

Discussion

One of the aims of this experiment was to determine whether age differences existed in the acquisition and transfer of visual numerosity skill. In particular, we investigated whether older adults engaged in general and/or specific learning for this task, and to what extent they relied on each type of learning. Another purpose of the experiment was to determine whether age differences in the acquisition and transfer of visual numerosity were related to age differences in working memory functioning and anxiety.

In terms of learning, both young and older adults became significantly faster during both the training and transfer phases of the visual numerosity task. In fact, a significant effect of practice was found for both age groups in both phases of the task. During the training phase, the performance of the young age group resembled an exponential function, whereas for the older age group performance resembled a power function. In the transfer phase, the performance of both age groups followed power functions. These functions indicated that both age groups achieved fast and efficient performance by the end of training and transfer. However, there was a significant main effect of age on reaction time for both the training and transfer phases of the experiment. This suggests that the young adults were consistently and significantly faster than the older adults during the entire visual numerosity task. The slower response time of older adults could be due to a decline in psychomotor speed that commonly occurs with age (Cerella, 1985). These results support our hypotheses and substantiate the findings of previous studies on aging and visual numerosity (e.g., Basak & Verhaeghen, 2003; Jenkins & Hoyer, 2000; Sliwinski, 1997).

Moreover, the benefits of practice on reaction time were found to be greater for young adults than for older adults in both phases of the visual numerosity task. This implies that the repetition of problems over many trials allows participants to learn the task more efficiently, and benefits young adults more than older adults. The learning rates of young and older adults during training and transfer were also obtained by looking at the learning functions for each age group. This revealed that the learning rate of young adults was faster than the learning rate of older adults, during both phases of the experiment. This replicates the findings of Jenkins and Hoyer (2000). Also, the amount of improvement (in reaction time) achieved was significantly greater for young adults than for older adults during the training phase, but the same for each age group during the transfer phase. This implies that older adults were able to improve to the same extent as young adults during the transfer phase, but not during the training phase. One possible explanation for this is that older adults became gradually familiar with the visual numerosity task during the training phase, and this familiarity aided their performance during transfer. Alternatively, older adults may have used a different type of learning strategy during the transfer phase that influenced the amount of improvement achieved. Finally, the level of accuracy was significantly greater for older adults than for younger adults over the entire experiment. This contradicts the results of Sliwinski (1997), who found that younger adults had greater accuracy levels than older adults in visual numerosity. It may be that older adults engaged in a 'speed-accuracy trade-off' in this experiment, whereby they sacrificed speed for the sake of accuracy. This would explain why the older age group was consistently slower than the younger age group, but more accurate than the younger age group. A study by Strayer and Kramer (1994) also found evidence for older adults engaging in speed-accuracy trade-offs during skill acquisition. The researchers suggest that older adults have a natural bias towards accuracy over speed, despite being told in experimental instructions to respond as quickly and as accurately as possible.

The poorer performance of older adults overall (e.g., consistently slower performance, less benefits from practice, slower learning rate, smaller improvement span) may also be explained by age-related impairments in the visual system. For example, a study by Moschner and Baloh (1994) found that the speed of smooth pursuit and saccadic eye movements decreases significantly with age. This would have a significant effect on the visual tracking rate of older adults. Since the task of visual numerosity involves the visual tracking of items (stars) on the screen for counting, this process may be slower in older adults compared to younger adults, as a result of biological changes in vision with aging. However, accuracy in visual tracking does not seem to be affected by aging (Moschner & Baloh, 1994), which explains why older adults were able to achieve higher accuracy levels compared to younger adults. Also, several studies have found that the useful field of view (i.e., the total area in which visual information can be acquired with one eye fixation) reduces in size with age (Ball, Beard, Roenker, Miller, & Griggs, 1988; Scialfa, Kline, & Lyman, 1987). This suggests that older adults are limited in how much information they can extract during a given fixation. The implication is also that when performing a visual numerosity task, older adults will observe smaller sections of the visual display, and will scan each section more slowly, compared to younger adults.

The effect of presenting new visual displays to young and older participants (i.e., displays with novel configurations) in a visual numerosity task was also investigated. It was hypothesized that both age groups would demonstrate partial transfer when new displays were presented. That is, it was predicted that both age groups would engage in a combination of specific and general learning to perform the task. This hypothesis was supported. The performance of both age groups was disrupted at transfer, which supports the findings of numerous studies that visual numerosity involves instance-specific learning (e.g., Jenkins & Hoyer, 2000; Lassaline & Logan, 1993; Logan, 1998). In fact, the performance of older adults was so impaired at the start of transfer that their reaction times actually returned to pre-training levels. This would normally imply that no positive transfer occurred for the older age group, and that they relied entirely on specific learning during training. However, when the training phase function of older adults was extrapolated to predict their performance during transfer, the actual performance of older adults fell within the confidence intervals of this extrapolated curve by the third block of transfer (Block 33). This suggests that older adults were able to transfer some of their skills from the training phase after all. Therefore, older adults seemed to engage in both specific and general learning for this task. Similarly, the performance of the young adults was impaired at the start of transfer, but their reaction times did not return to pre-training levels. This suggests that some positive transfer did occur for the younger age group, and that they relied on general learning during the training phase. However, when the training phase function of the young adults was extrapolated to predict their performance during transfer, the actual performance of young adults did not fall within the confidence intervals of this extrapolated curve at all, which suggests that they also relied on specific learning during training. Taken together, these results imply that the young age group engaged in both specific and general learning during training. This finding of partial transfer for young adults replicates the results of Green (1997).

In terms of skill acquisition theories, the results for both age groups do not support Logan's Instance theory. The fact that the performance of young adults did not return to pre-training levels in the transfer phase, and that the performance of older adults fell within the confidence intervals of the extrapolated training phase function, suggests that some positive transfer did occur for both age groups, despite the use of new stimuli in the transfer task. Therefore, both age groups learned a combination of general and specific skills during training, which can be best explained by Anderson's ACT* theory (1982). That is, participants probably used item-general productions to perform the counting task initially during training (e.g., a general production for marking items on a screen, for grouping items on the screen, for mapping numbers onto the items, for finding the total numerosity of items, and so on). Then, with practice, participants compiled multiple productions into single productions that were more efficient, faster and specific to certain displays. With practice, the likelihood of using item-specific productions instead of item-general productions to determine numerosity increased, thus causing the performance of participants to speed up, and placing less demands on working memory. However, these item-specific productions could not be used in the transfer phase, where participants were presented with a new set of visual displays. Therefore, the performance of participants became slower in the initial stages of transfer. Nonetheless, participants were still able to use item-general productions developed during training in order to perform the task at transfer, which explains why the performance of young adults did not return to pre-training levels, and why the performance of older adults quickly returned to their original learning curve from the training phase.

Although each age group learned general and specific skills, the nature of their transfer performance was very different, which implies that each age group probably learned these skills to varying degrees. For example, the finding that younger adults experienced a significantly smaller decline in reaction time from Block 30 to Block 31 compared to the older adults indicates that the amount of positive transfer was greater for younger adults than for older adults, and that younger adults relied more on general learning whereas older adults relied more on specific learning. On the other hand, the performance of the older age group during transfer returned to those levels predicted by their training phase function, whereas the performance of the younger age group during transfer did not. This suggests that the amount of positive transfer was greater for older adults than for younger adults, and that older adults relied more on general learning whereas younger adults relied more on specific learning. Therefore, these results directly contradict each other, and as such, it is impossible to determine the degree to which each age group engaged in each type of learning.

The present experiment also investigated the impact of working memory on the performance of participants. The three measures of working memory that were used in this experiment were the Digits Forward span, the Digits Backward span, and the Reading span. While the Digits Forward and Digits Backward measures correlated positively with each other for both age groups, the Reading Span measure did not correlate with either Digits Forward or Digits Backward measures. This suggests that Digits Forward and Digits Backward spans may measure similar aspects of working memory, whereas Reading span may measure a different aspect of working memory.

To determine whether a relationship existed between working memory and performance, correlations were calculated between measures of working memory and accuracy for each age group during skill acquisition. It was predicted that measures of working memory would correlate positively with the accuracy levels of each age group during both phases of the visual numerosity task. This hypothesis was supported. For the young age group, accuracy in training was positively associated with Digits Backward scores, and accuracy in transfer was positively associated with Reading span scores. For the older age group, accuracy in training was positively associated with Reading span scores, and accuracy in transfer was positively associated with Digits Forward and Reading span scores. This implies that the larger the working memory spans of participants, the higher their accuracy levels, and vice versa.

Correlations were also calculated between measures of working memory and mean reaction times for each age group during skill acquisition. It was predicted that measures of working memory for both age groups would correlate negatively with reaction time during both phases of the visual numerosity task. For the young age group, the results revealed significant negative correlations between working memory and mean reaction times during both phases of the experiment, such that participants with larger working memory spans demonstrated faster reaction times. For example, a small number of significant correlations were found in the first third of the training phase, and a high number of significant correlations were found during the middle and last third of the training phase. During the transfer phase, a small number of correlations were found in the first two thirds, and a large number of correlations were found in the last third. The correlations were mostly between the Digits Forward measure (which measures the storage component of working memory) and mean reaction times during both phases. The implication of these results is that for the young age group, the storage component of working memory played a significant role in performing the task during both phases of the experiment. Moreover, the association between working memory span and mean reaction times seemed to become stronger as each phase progressed. It could be that working memory was involved in the storing and retrieval of instances from long-term memory in the later stages of each phase (Brigman & Cherry, 2002).

On the other hand, only a small number of significant correlations occurred between working memory and mean reaction times for the older age group. These significant correlations occurred in the middle and final third of the training phase, and were mainly between the Digits Backward measure (a measure of both the storage and processing components of working memory) and mean reaction times However, no significant correlations were found between working memory span and mean reaction times during the transfer phase. This suggests that differences in the functional capacity of working memory were related to differences in reaction times during the training phase, but not during the transfer phase, for older adults. That is, older adults with larger working memory capacities were able to perform the task faster than those with smaller working memory capacities during the training phase. However, individual differences in working memory capacity had no bearing on performance during the transfer phase, such that all older adults had sufficient working memory capacity to perform the task.

Therefore, it seems that the functional capacity of working memory was associated with the accuracy levels of both age groups during both phases of the experiment. Moreover, the storage component of working memory was associated with the reaction times of younger adults during training and transfer, and the storage and processing components of working memory were related to the reaction times of older adults during training. It is unclear why working memory measures for the older adults did not correlate with their reaction times during the transfer phase. It could be that the task did not place enough demands on working memory during transfer, such that even older adults with smaller working memory spans were able to perform it. Therefore, future experiments could increase the complexity of the task by increasing the complexity of the visual displays (e.g., adding distractors to displays) or by asking participants to perform another working memory task concurrently. Alternatively, the performance of older adults (especially during the transfer phase) may be more related to differences in speed of information-processing rather than differences in working memory functioning (Lincourt, Rybash, & Hoyer, 1998). Indeed, the results of some studies have revealed that the speed of information-processing can better account for age-related differences in performance than working memory (e.g., Salthouse, 1991; Salthouse, 1992; Salthouse & Coon, 1994; Salthouse & Kersten, 1993). Therefore, measures such as the Digit Symbol Coding subtest or the Symbol Search subtest from the Wechsler

Adult Intelligence Scale – Third Edition (Wechsler, 1997) should have been included in the present experiment, to test the speed of information-processing of young and older adults.

In terms of the working memory measures, it was hypothesized that young and older adults would perform equally well on the Digits Forward task, which measures the storage component of working memory (in particular, the phonological loop). The results did not support this hypothesis, with the mean Digits Forward scores for young adults being significantly higher than those of older adults. This implies one of two things: either the phonological loop becomes impaired with age (which does not support the results of previous studies), or the lower scores on Digit Span are due to the slower articulation rate of this sample of older adults (Kynette, Kemper, Norman, & Cheung, 1990). A study by Gerhand (1994, cited in Phillips & Hamilton, 2001) found that when the variance due to articulation rate is statistically removed, the age difference disappears in Digit Span scores. Therefore, the poorer performance of older adults may have been caused by slower articulation rates rather than impaired phonological loop functioning.

It was also predicted that the mean scores for Digits Backward and Reading Span would be lower for older adults than for younger adults, because these tasks involve central executive functioning, which is thought to deteriorate with age. While our analysis found that Reading Span scores were indeed significantly lower for older adults than for younger adults, this was not found with the Digits Backward scores. Therefore, it is unclear whether central executive functioning was impaired in the older adults or not. Several researchers have claimed that central executive functioning can remain intact with age (e.g., Kramer, Humphrey, Larish, Logan, & Strayer, 1994; McDowd, 1997; Sullivan & Faust, 1993). For example, a study by

Kramer and Atchley (2000) found that older adults were able to inhibit familiar elements in a visual display while focussing on novel elements (a process called 'visual marking') as accurately as younger adults, although more slowly than younger adults. It is thought that the central executive controls this process of inhibition, and that the central executive therefore remains relatively intact with age.

Unfortunately, one of the major limitations of the present experiment is that participants were not given a task to measure the storage and processing components of the visuo-spatial sketchpad. An ideal task to measure this would have been the Spatial Span task from the Wechsler Memory Scale – Third Edition (Wechsler, 1997). In this task, the participant is presented with a board with 10 boxes in different spatial locations. The examiner then taps the boxes in a certain sequence, and the participant is required to repeat this sequence by tapping the boxes in the correct order. At first, participants are presented with a sequence of two blocks, but the sequence span increases over the trials. In the Spatial Span Forward task, participants must repeat the sequence as the examiner presented it. However, in the Spatial Span Backward task, participants must repeat the sequence in the reverse order, which requires visuo-spatial processing. Therefore, the Spatial Span Forward task measures the storage component of visuo-spatial working memory, whereas the Spatial Span Backward task measures both the storage and processing components of visuo-spatial working memory. It is probable that young adults would have scored significantly higher on this task compared to older adults, if the measure had been administered in this experiment. This is because the VSSP is thought to deteriorate with age. However, it seems that older adults engaged in some visual memory-based learning for this experiment (i.e., item-specific learning), which suggests that their visuo-spatial sketchpads were able to encode and process the information from the basic visual displays presented. Indeed, studies have shown that older adults have no difficulty in processing and storing low-level visual-spatial information (Faubert, 2000; Faubert & Bellefeuille, 2002).

It is feasible that age-related changes in working memory (especially the deterioration of executive functioning) would affect the amount of initial recovery for each age group during the transfer phase. This is because initial recovery during transfer requires the use of counting algorithms in order to determine the numerosity of new visual displays, and these counting algorithms place a load on central executive functioning. Therefore, the amount of initial recovery should be greater for participants with intact central executive functioning compared to those with impaired central executive functioning. The results from this experiment were that the older adults displayed a greater amount of initial recovery than the younger adults. This suggests that perhaps the central executive functioning of older adults in the present experiment was intact, and that the older adults were able to perform the counting process as well as the younger adults. The finding that Digits Backward scores were not significantly different for the two age groups lends support to this theory. Furthermore, it is also possible that the central executive functioning of younger adults was less efficient compared to that of older adults during transfer, due to the negative effects of anxiety (discussed later in this section).

It was also possible that the working memory span of participants would affect their speed of recovery during the transfer phase. This is because recovery in the transfer phase also requires participants to use counting algorithms (which require central executive processing) in order to determine the numerosities of new visual displays. Since central executive functioning is thought to be impaired in older adults, the speed of their recovery in the transfer phase should be slower than for younger adults. That is, older adults were expected to take longer to return to their Block 30 reaction times in the transfer phase, compared to younger adults. However, this did not occur. The results indicated that both age groups returned to their Block 30 reaction times by Block 42 of the transfer phase. Therefore, the speed of recovery in the transfer phase was the same for both age groups. These results imply that older adults are as capable of algorithmic processing as younger adults. That is, the results further support the notion that central executive functioning can remain intact with age. However, the lack of significant correlations between working memory functioning and reaction times for older adults during transfer suggests that the visual numerosity task was not placing enough demands on working memory. Therefore, it is possible that central executive functioning was actually impaired in this age group (as indicated by their lower Reading Span scores), but was still efficient enough to perform the task.

Finally, the impact of anxiety on the performance of participants was determined. All three measures of anxiety (i.e., STAI-1, STAI-2 and Trait anxiety) correlated significantly with each other for the young age group. However, trait anxiety did not correlate significantly with the STAI-2 for the older age group. This implies that the two questionnaires were measuring different aspects of anxiety for older adults.

Nevertheless, it was hypothesized that measures of state or trait anxiety would correlate negatively with performance in terms of reaction time and accuracy. This hypothesis was partially supported. For the young age group, a small number of significant correlations were found between state/trait anxiety and reaction time during the training phase. The highest number of significant correlations occurred in the last third of the training phase. A much greater number of significant correlations were found between state/trait anxiety and reaction time during the transfer phase, especially during the middle and final third. These results suggest that higher levels of anxiety were associated with slower reaction times for the young age group, and that the impact of anxiety increased as the training and transfer phases progressed. However, no significant correlations were found between measures of anxiety and accuracy in either phase of the experiment for the young age group.

For the older age group, a very small number of significant correlations were found between state anxiety and reaction time during the training phase. The highest number of significant correlations occurred in the last third of the training phase, suggesting that the negative impact of state anxiety on reaction times may have increased as the training phase progressed. Furthermore, only two significant correlations were found between state anxiety and reaction time during the transfer phase. This implies that state and trait anxiety had a minimal impact on the performance of older adults. In addition, no significant correlations were found between measures of anxiety and accuracy in either phase of the experiment for the older adults. Therefore, it seems that higher levels of anxiety were associated with slower reaction times for young adults and (to a lesser extent) older adults during both phases of the experiment. However, high levels of anxiety did not seem to have an effect on the accuracy of young and older adults during either phase of the experiment.

It was also predicted that measures of anxiety would correlate negatively with measures of working memory. Analysis for the young age group revealed a significant negative correlation between state anxiety and the Digits Backward task, which implies that higher levels of state anxiety in young adults were associated with lower working memory spans. This supports the claims from several studies that anxiety interferes with working memory functioning (e.g., Ashcraft & Kirk, 2001; Hopko, Ashcraft, & Gute, 1998; Idzikowski & Baddeley, 1983a; Idzikowksi & Baddeley, 1987; Moldawsky & Moldawsky, 1952; Mueller, 1980). Furthermore, the effect of anxiety on the working memory span of young adults may explain why the amount of initial recovery in the transfer phase was smaller for the younger age group than for the older age group. Indeed, it is possible that high levels of state anxiety interfered with central executive functioning in the young age group, which consequently affected their algorithmic processing ability during the transfer phase. In contrast, no significant correlations were found between anxiety and working memory for the older age group. This could mean that anxiety did not interfere with working memory functioning for the older adults. Alternatively, the lower levels of variance in two anxiety measures for the older adults may explain why significant correlations were not found between anxiety and working memory for this age group compared to the younger age group.

The final hypothesis was that older adults would display the same levels of state anxiety as younger adults, but lower levels of trait anxiety than younger adults. This hypothesis was partially supported. While the STAI-1 scores for both young and older adults were the same, the STAI-2 scores for older adults were lower than those for younger adults. Similarly, the trait anxiety of older adults was lower than that of younger adults. The lower levels of state and trait anxiety in older adults can be attributed to older adults becoming more psychologically stable with age, and better able to cope with stressful situations compared to younger adults. This has been found in previous studies (e.g., Coolidge et al., 2000; Nakazato & Shimonaka, 1989).

In summary, both young and older adults were able to learn a visual numerosity task. Although older adults learned the task more slowly than younger adults, they achieved higher levels of accuracy than younger adults. Both age groups seemed to engage in a combination of general and specific learning for this task, although possibly to different extents. Furthermore, working memory played a significant role in learning the task for both age groups. For the young age group, working memory span was related to accuracy and reaction times during both training and transfer. For the older age group, working memory span was related to accuracy and reaction times during training, and accuracy during transfer. The fact that working memory was associated with the performance of both young and older adults suggests that age differences in skill acquisition may be related to age differences in working memory for visual numerosity tasks. Moreover, anxiety seemed to affect the reaction times of young adults and (to a lesser extent) older adults during both phases of the experiment. In particular, a relationship between state anxiety and working memory functioning was found for the young age group. Older adults also had lower levels of state/trait anxiety than younger adults in this experiment, and this may have provided them with some benefits during skill acquisition. Therefore, it may be that differences in skill acquisition are related to differences in the anxiety levels of participants.

These findings have great practical implications for society. The fact that both young and older adults learned a cognitive/perceptual skill using a combination of general and specific learning suggests that both age groups can be taught these skills in a similar way. That is, older adults seem as capable of engaging in memory-based, item-specific learning as younger adults, although the two age groups probably do so to varying degrees. This implies that instructors can teach both age groups item-specific information about a cognitive/perceptual skill, as well as item-general information.

The present experiment also tested the popular myth that older adults are incapable of learning new skills. However, the results from this experiment revealed that older adults were not only able to learn a novel cognitive/perceptual task, but they were able to achieve fast and efficient performance in this task, they could improve as much as younger adults with practice (in the transfer phase) and they achieved higher levels of accuracy than younger adults. Furthermore, the amount of recovery in the initial stages of transfer was greater for older adults than for younger adults, suggesting that the older participants were capable of adapting quickly to a new task. Older adults were also quickly able to return to the levels of performance predicted by their training phase function, which implies that they were able to retain and use some of the general skills learned in training. This ability to retain general skills is beneficial in the workplace, if a worker is transferred from one task to another that is the same in structure, but uses different items or information. However, as in Experiment 1, the older adults in this experiment were volunteers from the community who seemed physically healthy (89.4% denied having health problems affecting performance) and mentally intact. Therefore, the results from this experiment further support the notion that aging does not necessarily bring about a decline in learning ability, and that older adults who stay physically and mentally healthy have little difficulty in acquiring and transferring new skills.

Chapter 7: General Discussion and Conclusions

The results of Experiments 1 and 2 contribute significantly to knowledge about biological and cognitive aging. In the area of cognitive aging, the findings provide information about skill acquisition and transfer, cognitive skill learning, perceptual skill learning, implicit learning, working memory, anxiety, and speed of information processing. In terms of biology, the results provide information about changes in the visual system, the nervous system and the brain with aging.

With regard to skill acquisition, the present thesis investigated two theories: Anderson's ACT* theory (1982, 1983, 1987) and Logan's Instance theory (1988). Both theories propose that skill acquisition involves a shift from controlled processing to automatic processing, whereby controlled processing is slow, error-prone, effortful and available to conscious awareness while automatic processing is fast, error-free, effortless and unavailable to conscious awareness. According to ACT* theory, performance becomes automatic when declarative knowledge is compiled into procedural knowledge (productions). With practice, multiple productions are compiled into single productions that are efficient, specific, and fast. These productions are not accessible for verbal reporting. The result is that performance on the task speeds up and places less demands on working memory. In contrast, the Instance theory states that performance initially relies on the use of a general problem-solving algorithm. However with practice, solutions to problems are remembered and stored in memory as 'instances'. Eventually, performance starts to depend completely on the stored instances, because the retrieval of instances becomes consistently faster than the execution of a general algorithm.

In both tasks examined in Experiments 1 and 2, the performance of young and older adults became faster and more efficient by the end of practice, suggesting that both age groups learned a new skill. In fact, a significant effect of practice was found for both age groups in each task. However, the benefit of practice on reaction time was greater for young adults than for older adults during both phases of the visual numerosity task, and during the transfer phase of the arithmetic task. This implies that the repetition of arithmetic problems or visual displays brings about a greater speed-up in reaction time in younger adults compared to older adults.

Furthermore, when the performance of young and older adults was graphed against practice for each task, the graphs resembled either power or exponential functions. An exponential function (rather than a power function) provided a better fit for the training data of the young adults in the visual numerosity task, which suggests that the power law of practice is not always 'ubiquitous', as thought by Newell and Rosenbloom (1981). The exponential equation has actually been found to be a good fit for conventional perceptual-motor tasks (Digman, 1959; Noble, Salazar, Skelley, & Wilkerson, 1979). Since visual numerosity can be described as a perceptual-motor task, this might explain why the exponential function was a good fit for some of the data.

However, the issue of which function provides a better fit to learning data (in general) still remains unresolved in the literature. Our finding that an exponential function provides a better fit for some of the data compared to a power function supports the idea that a power curve is more appropriate in some learning conditions while an exponential curve is more appropriate in other learning conditions (e.g., Carlson, 1999; Heathcote, Brown & Mewhort, 2000; Lane, 1987). However, little research has been conducted on the characteristics of these conditions, and therefore the issue remains unclear. Although it was never the goal of the current thesis to resolve this issue, our results provide an interesting opportunity for future research in this field.

When the slopes of all the learning functions were analysed, it was clear that the learning rates of the young adults were faster than those of the older adults, for both the arithmetic task and the visual numerosity task. According to Jenkins and Hoyer (2000), the faster learning rate of young adults indicates that they take less time to switch from algorithmic performance to memory-based performance compared to older adults. However, the amount of improvement within each learning phase was the same for both age groups in both phases of the arithmetic task, and in the transfer phase of the visual numerosity task. Therefore, although older adults were slower at learning each task, they were still able to achieve the same amount of improvement as younger adults with practice (in most phases).

The experiments also investigated the notion of the transfer of skill. Transfer refers to "the study of how knowledge acquired in one situation applies (or fails to apply) in other situations" (Singley & Anderson, 1989, p. 1). Skills that can be applied to contexts other than the one in which they were acquired are often referred to as 'general skills' whereas skills that are specific to the context in which they were acquired are often referred to as 'specific skills' (Singley & Anderson, 1989). Anderson's ACT* theory (1982, 1983, 1987) is a general theory of skill acquisition, which states that skills can transfer from one task to another depending on the extent to which the same productions are involved in performing the two tasks. Therefore, the amount of transfer should be high when going from one set of problems to another set of similar problems that can be solved using the same productions. In contrast, Logan's Instance Theory (1988, 1990) is a specific theory of skill acquisition, which states that transfer to a new context is possible only if the new task involves specific events that have been encountered in the old task. That is, transfer will only occur if the new task can be performed by retrieving the same instances that were used in the old task. If this is not possible, then performance will depend on the execution of an algorithm, and reaction times will revert to pre-practice levels. Thus, Anderson's ACT* theory predicts complete transfer between two similar tasks, whereas Logan's Instance theory predicts no transfer between similar tasks.

However, many researchers have found that experimental results differ from those predicted by the skill acquisition theories. The common finding is that participants actually demonstrate partial positive transfer, such that their performance is severely impaired at transfer, but does not return to pre-training levels (e.g., Charness & Campbell, 1988; Green, 1997; Greig & Speelman, 1999; Touron, Hoyer, & Cerella, 2001). Furthermore, the performance of participants during transfer often returns to levels predicted by their training phase function, which implies that some general skills from training are retained at transfer (Greig & Speelman, 1999; Speelman & Kirsner, 2001). These results are at odds with Logan's Instance theory. However, the results can actually be explained by Anderson's ACT* theory. According to ACT* theory, participants can initially develop item-general productions to solve problems. With practice, participants can develop item-specific productions that are specific for certain problems. In the transfer phase, the item-specific productions developed in training are no longer appropriate. Therefore performance is slower in the initial stages of the transfer phase compared to the end stages of the training phase. However, participants are still able to use the item-general productions developed during training, which explains why their performance during the transfer phase often returns to levels predicted by the training phase function, and why performance during the transfer phase does not return to pre-training levels.

In Experiments 1 and 2, participants were presented with either an arithmetic task or a visual numerosity task during the training phase, and were presented with the same task again during the transfer phase. However, although the structures of the tasks remained the same at transfer, the stimuli in the tasks were changed. That is, participants were presented with new arithmetic problems during the transfer phase of the arithmetic task, and new visual displays during the transfer phase of the visual numerosity task. Changing the stimuli in this way meant that participants were not able to use past solutions (instances) stored in memory to solve these new problems or displays. That is, participants had to revert to using general algorithms to solve the problems/displays. Therefore, it was predicted that the performance of both age groups would be severely impaired at transfer. However, it was hypothesized that the performance of participants would not return to pre-training levels, since they would still be able to use item-general productions developed during training. It was also expected that the transfer performance of participants would eventually return to those levels predicted from their training phase performance. That is, the performance of participants during transfer was expected to eventually lie within the 95% confidence intervals of their training phase function. Thus, both age groups were expected to show partial positive transfer for each task.

The results from the mental arithmetic task were that both age groups did show partial positive transfer, although in different ways. For the young age group, their reaction times in the initial stages of transfer returned to pre-training levels, which suggests that they learned specific skills during training that were not easily transferable. However, when the training data function for young adults was extrapolated to predict their performance during transfer, their transfer performance eventually fell within the confidence intervals of this extrapolated function, which indicates that they learned general skills during training, and that they retained these skills for the transfer phase. Therefore, the young age group demonstrated partial positive transfer for mental arithmetic skill, and this suggests that they learned the task by engaging in both specific and general learning strategies. For the older age group, their reaction times in the initial stages of transfer slowed down dramatically, which suggests that they relied heavily on specific learning during training. However, their reaction times did not return to pre-training levels at transfer, which implies that they also relied on general learning during training. Furthermore, when the learning curve for older adults during training was extrapolated to predict their performance during transfer, their reaction times eventually fell within the 95% confidence intervals of their extrapolated training function. This result supports the conclusion that older adults also engaged in a combination of general and specific learning during training.

Similarly, the results from the visual numerosity task were that both age groups demonstrated partial positive transfer, although in different ways. For the young age group, reaction times became significantly slower at transfer, but did not return to pre-training levels. This indicates that some positive transfer of skills occurred, and that participants were engaged in both general and specific learning during training. Furthermore, the transfer performance of young adults did not return to that predicted by their training phase function, which again implies that young adults engaged in specific learning for this task. For the older age group, reaction times became so slow at transfer that they returned to pre-training levels, which would suggest that no positive transfer occurred, and that older adults engaged only in specific learning. However, when the training phase function of older adults was extrapolated to predict their performance during transfer, the actual performance of older adults during transfer fell within the confidence intervals of this extrapolated function. This suggests that older adults were able to transfer some general skills from the training phase after all. Therefore, older adults seemed to engage in both specific and general learning for this task as well.

Although both age groups seemed to rely on a combination of general and specific learning for both tasks, the transfer performance of each age group was quite different for each task. For example, in the arithmetic task, the performance of younger adults returned to pre-training levels at transfer while that of older adults did not, but both young and older adults returned to their original training phase function (as extrapolated from the training data). In the visual numerosity task, however, the performance of older adults returned to pre-training levels at transfer while that of younger adults did not, and the performance of older adults returned to that predicted by their training phase function while that of younger adults did not. These differences in transfer performance suggest that young and older adults may have been engaging in general and specific learning to different extents in these tasks.

It is also interesting to note that the transfer performance of young and older adults differed from one task to another. This suggests that maybe young and older adults changed their learning styles depending on the type of task they were learning (i.e., cognitive vs. cognitive/perceptual). For example, it is possible that a task such as mental arithmetic requires more mental activity and processing, while a task such as visual numerosity requires more sensory/perceptual activity and processing. It may be that the differences in the requirements of each task actually affected how participants then learned each task. Furthermore, older adults achieved greater levels of accuracy in the perceptual task compared to younger adults, whereas there was no difference in accuracy levels in the cognitive task. This implies that older adults sacrificed speed for accuracy in the perceptual task, but not in the cognitive task. One possible explanation for this is that aging is associated with a deterioration of the visual system, and maybe older adults compensated for this deterioration by responding more cautiously and accurately during the perceptual task. The implication of these results is that young and older adults probably learn cognitive and perceptual skills in different ways, and this consequently affects how they will perform these skills.

Another important point is that the groups of older adults recruited for Experiments 1 and 2 came from different sources. As a consequence, the demographic characteristics of the older adults varied across the two experiments. For example, the older adults recruited for Experiment 2 were about 4 years older on average, they were mostly female, and they were somewhat less educated than the older adults recruited for Experiment 1. It is generally believed that older age and lower levels of education can impact negatively on the performance of adults in intellectual tasks (Cronbach, 1984). Furthermore, several studies have found that males are generally better at learning mathematical and spatial tasks compared to females (eg. Hedges & Nowell, 1995; Voyer, Voyer, & Bryden, 1995). Therefore, the older adults in Experiment 2 may have been at a disadvantage when learning new skills, compared to those in Experiment 1. The difference in demographic details may explain why the older adults in Experiment 2 returned to their pretraining levels at transfer whereas those in Experiment 1 did not, and why the older adults in Experiment 2 had significantly lower Digits Forward and Reading Span scores compared to younger adults, while those in Experiment 1 did not. These differences in results may be attributed to the different characteristics of the sample groups.

The findings from Experiments 1 and 2 also provide information about implicit learning. Implicit learning refers to the "learning [of] complex information without complete verbalizable knowledge of what is learned" (Seger, 1994, p. 163). It is an unconscious process whereby the individual acquires knowledge without deliberately trying to do so. Conversely, explicit learning involves the conscious use of strategies to gain knowledge about a task (O'Brien-Malone & Maybery, 1998). Some research studies have found that implicit learning remains intact in older adults (e.g., Hashtroudi, Chrosniak, & Schwartz, 1991; Howard & Howard, 1989; Moscovitch, Winocur, & McLachlan, 1986; Myers & Conner, 1992) whereas other studies have found that implicit learning becomes impaired with age (e.g., Feeney, Howard, & Howard, 2002; Harrington & Haaland, 1992; Howard & Howard, 2001). Both the mental arithmetic task and the visual numerosity task in our experiments can be considered implicit learning tasks, because participants were never told about the repetition of problems/displays, nor were they told to encode the problems/displays in any way. In fact, the visual numerosity task has been described as an implicit learning task by Chun and Jiang (1998). They proposed that participants learn visual numerosity by implicitly storing the contextual information in visual displays as 'instances' in memory. In the same way, participants could implicitly store specific information from arithmetic problems as instances. Therefore, both tasks can be learned implicitly and without conscious awareness. The results from the present experiments were that both age groups improved their performance with practice and became fast and efficient in these tasks. This indicates that both young and older adults were able to learn implicit tasks, and confirms earlier findings that implicit learning remains intact with age.

In terms of working memory, Experiments 1 and 2 showed that working memory span could be associated with the performance of participants. However, working memory seemed to have a greater association with performance for the visual numerosity task than for the mental arithmetic task. For example, during the arithmetic task, working memory was related to accuracy levels and reaction times of the young age group during the transfer phase, but not during the training phase. Working memory was not related to accuracy levels or reaction times at all for the older age group. During the visual numerosity task however, working memory was related to the accuracy levels and reaction times of the younger age group during both phases of the experiment. Similarly for the older age group, working memory was related to the accuracy levels during both phases of the experiment, but only slightly related to reaction times during the training phase. The correlations were such that higher working memory spans were associated with higher levels of accuracy and faster reaction times, whereas lower working memory spans were associated with lower levels of accuracy and slower reaction times. This pattern of results suggests that individual differences in working memory span can be related to individual differences in skill acquisition and performance.

However, the lack of correlation between working memory span and performance in some cases implies that differences in the working memory spans of individuals did not always relate to differences in their performance. In fact, a lack of correlation between working memory span and performance suggests that all individuals possessed sufficient working memory capacity to perform the task. For example, in the mental arithmetic task, there was a lack of association between working memory span and reaction times for the older age group during training and transfer, and for the younger age group during training. This may have occurred because the arithmetic task did not place enough demands on working memory, so that even participants with small working memory spans (i.e., with smaller storage capacity and less efficient processing) were able perform it without difficulty. Furthermore, the older adults in the sample were well educated, such that they may have found the arithmetic problems too easy and not taxing enough for working memory involvement. Future experiments could increase the complexity of the arithmetic task by using hierarchical problems, multiple digit problems, or asking participants to perform a secondary task (e.g., a memory load task) at the same time as the primary task. Similarly in the visual numerosity task, working memory measures for the older adults did not correlate with their reaction times during transfer. Again, it could be that the task did not place enough demands on working memory during transfer, such that even older adults with smaller working memory spans were able to learn it. Therefore, future experiments could increase the complexity of the visual numerosity task by increasing the complexity of the visual displays (e.g., adding distractors to displays) or by asking participants to perform another working memory task concurrently. Such increases in task complexity could increase the involvement of working memory, which could result in a larger number of significant associations with performance. Alternatively, the performance of older adults may be more related to differences in speed of information-processing rather than differences in working memory functioning (Lincourt, Rybash & Hoyer, 1998). Therefore, measures such as the Digit Symbol Coding subtest or the Symbol Search subtest from the Wechsler Adult Intelligence Scale – Third Edition (Wechsler, 1997) should have been included in both experiments, to assess differences in the speed of information-processing in young and older adults.

To further understand the role of working memory in skill acquisition, working memory was conceptualised as the multi-component system described by Baddeley and Hitch (1974). In their model of working memory, a general processing system called the ‘central executive’ supervises and coordinates two subordinate ‘slave systems’ (Baddeley, 1998). The slave system responsible for manipulating speech-based information is called the ‘articulatory loop’ or the ‘phonological loop’, and the slave system responsible for manipulating visual information is called the ‘visuo-spatial sketchpad’ (Baddeley, 1998). The studies conducted on working memory and aging have found that the phonological loop remains intact with age (e.g., Dolman, Roy, Dimeck & Hall, 2000; Phillips & Hamilton, 2001; Rouleau & Belleville, 1996), the central executive deteriorates with age (e.g., Coffey, Wilkinson, Parashos, Soady, Sullivan, Patterson, Figiel, Webb, Spritzer, & Djang, 1992; Coleman & Flood, 1987; Craik, Morris, & Gick, 1990) and the visuo-spatial sketchpad deteriorates with age (e.g., Cerella, Poon & Fozard, 1981; Chagnon & McKelvie, 1992; Dror & Kosslyn, 1994) although it seems to stay intact for basic visual information (Faubert, 2000; Faubert & Bellefeuille, 2002). These findings were partially tested in Experiments 1 and 2 by asking young and older adults to perform the Digits Forward task (which measures phonological loop storage), the Digits Backwards task (which measures central executive functioning) and the Reading Span Task (which measures central executive functioning). In Experiment 1, the mean Digits Forward scores did not differ significantly between the age groups, which implies that phonological loop functioning remains intact with age. However, the mean Digits Forward scores in Experiment 2 did differ significantly between age groups, with younger adults achieving much higher scores than older adults. While this could mean that the phonological loop does not remain intact with age, an alternative explanation is that older adults have slower articulation rates than younger adults, which then affects how much information they can retain in their phonological loops (Kynette, Kemper, Norman, & Cheung, 1990). As for the central executive measures, Experiment 1 found that older adults had significantly lower Digits Backwards scores than younger adults, but the same Reading Span scores as younger adults. On the other hand, Experiment 2 found that older adults had significantly lower Reading Span scores than younger adults, but the same Digits Backwards scores as younger adults. Therefore, it is difficult to ascertain from these results whether central executive functioning remained intact or declined in our sample groups of older adults.

Several researchers have proposed that the central executive and the phonological loop are the main components responsible for processing information during mental arithmetic tasks (e.g., Baddeley, 1966a; Baddeley & Logie, 1999; Blankenberger & Vorberg, 1997; De Rammelaere, Stuyven, & Vandierendonck, 1999; Furst & Hitch, 2000; Hecht, 2002; Logie, Gilhooly, & Wynn, 1994). On the other hand, all three components of working memory seem to play an important role in processing information during visual numerosity tasks (Baddeley & Logie, 1999; Buchner, Steffens, Irmen, & Wender, 1998; Engle, Kane, & Tuholski, 1999; Green, 1997; Hitch, 1978; Lassaline & Logan, 1993; Logan, 1998; Logie & Baddeley, 1987; Nairne & Healy, 1983; Tuholski, Engle, & Baylis, 2001). Therefore, if the phonological loop and the VSSP remain intact (for basic visual information) with age, this suggests that any processing problems experienced by older adults can mostly be attributed to a decline in central executive functioning. This was investigated in Experiments 1 and 2, by looking at the amount of initial recovery (i.e., the decline in reaction time from Block 31 to Block 32) during transfer, and the speed of full recovery (i.e., how long it takes participants to return to Block 30 reaction times during transfer), for each age group. This is because initial and full recovery during transfer can only be achieved using algorithmic processing, since participants can no longer rely on memory-based or item-specific skills learned during training. This algorithmic processing is thought to be controlled by the central executive. In Experiment 1, the amount of initial recovery in the transfer phase was the same for both age groups, and both age groups took the same amount of time to return to their Block 30 reaction times. In Experiment 2, the amount of initial recovery in the transfer phase was greater for older adults compared to the younger adults, and both age groups again took the same amount of time to return to their Block 30 reaction times. These results indicate that older adults were as capable (if not more capable) of algorithmic processing compared to younger adults, which suggests that the central executive was intact in these participants. However, it must be remembered that the older adults recruited for these experiments were volunteers who seemed mentally and physically healthy. Therefore, older adults may be able to retain their central executive functioning if they remain mentally and physically active in their lives. Also, it is always possible that central executive functioning was impaired in these older adults, but still sufficient enough to perform the two tasks (especially if neither task was placing enough demands on working memory, as discussed before).

Although most research has found that central executive functioning declines with age, the findings from Experiments 1 and 2 suggest that the central executive may remain intact with age. Several studies have proposed this. For example, a study by Kramer and Atchley (2000) found that older adults were able to inhibit familiar elements in a visual display while focussing on novel elements (a process called 'visual marking') as accurately as younger adults, although they were slower than younger adults. It is thought that the central executive controls this process of inhibition, and that the central executive therefore remains relatively intact with age. In a study by Kramer, Humphrey, Larish, Logan and Strayer (1994), the researchers found that older adults showed the same inhibitory processing effects as younger adults in visual search tasks. For example, both age groups showed the same response compatibility effects (i.e., their reaction times became slower when targets required a different response to distractors in visual search displays), they showed the same negative priming effects (i.e., their reaction times become slower when distractors from past trials were used as targets in current visual search trials), they showed the same spatial pre-cuing effects (i.e., older adults benefited as much as younger adults when a location cue was presented before a target in visual search displays), and they showed the same self-reported cognitive failures (i.e., older adults did not report significantly more cognitive failures than younger adults). These results imply that some inhibitory processes (controlled by the central executive) may remain intact with age. Finally, a study by Sullivan and Faust (1993) found that older adults could be as efficient as younger adults at suppressing semantic or identity information during a negative priming task (i.e., when distractors from past trials are used as targets in current visual search trials). This ability to suppress information is again a central executive function, which seems to remain relatively intact with age. Therefore, it is possible that some amount of central executive functioning was retained in our sample of older adults after all.

Both Experiments 1 and 2 also found that anxiety was strongly associated with the performance of participants. For the young adults, significant correlations were found between anxiety and reaction times for both phases of the mental arithmetic task, and for both phases of the visual numerosity task. That is, higher levels of anxiety were associated with slower reaction times. However, anxiety was not related to accuracy levels in either task. For the older age group, significant correlations were found between anxiety and reaction times during both phases of the mental arithmetic task, and during both phases of the visual numerosity task. Again, higher levels of anxiety were associated with slower reaction times. Furthermore, significant correlations were found between anxiety and accuracy in the training phase of the mental arithmetic task, with higher levels of anxiety being related to lower levels of accuracy. However, no significant correlations were found between anxiety and accuracy in the transfer phase of the mental arithmetic task, or in either phase of the visual numerosity task. Overall, these results suggest that anxiety had a detrimental effect on the performance of young and older adults during skill acquisition. This supports the findings of numerous other studies (e.g., Ashcraft, 2002; Ashcraft & Faust, 1994; Hopko, McNeil, Lejuez, Ashcraft, Eifert, & Riel, 2003; Kellogg, Hopko, & Ashcraft, 1999; Leon, 1989; MacLeod & Donnellan, 1993; Markham & Darke, 1991; Tohill & Holyoak, 2000).

The relationship between anxiety and working memory was also investigated in Experiments 1 and 2. For the young age group, significant correlations were found between trait anxiety and working memory span in the mental arithmetic task, and between state anxiety and working memory span in the visual numerosity task. These correlations indicated that high levels of anxiety were associated with smaller working memory spans for young adults during skill acquisition. This supports the claim of many researchers that a high level of anxiety interferes with working memory functioning (e.g., Ashcraft & Kirk, 2001; Hopko, Ashcraft, & Gute, 1998; Idzikowski & Baddeley, 1983a; Idzikowksi & Baddeley, 1987; Moldawsky & Moldawsky, 1952; Mueller, 1980). In contrast, the older age group showed no significant correlations between anxiety and working memory span in either task. Thus, it seems that older adults were immune to the effects of anxiety on working memory. It is possible that anxiety affected the working memory functioning of younger adults but not that of older adults because the older adults had significantly lower levels of state and trait anxiety compared to the younger adults during both tasks. It may be that a certain amount of anxiety is necessary before it interferes with working memory functioning, and that young adults reached this amount of anxiety, whereas older adults did not. Alternatively, it is possible that the low levels of variance in the anxiety scores of the older adults in both experiments prevented any significant correlations from being found between anxiety and working memory. The finding that standard deviations were lower for the older adults than for the younger adults in all three anxiety measures of Experiment 1, and in two of the anxiety measures of Experiment 2, provides some support to this theory.

In any case, the interaction between anxiety and working memory in young adults may explain some of the age differences found in each task. For example, during the transfer phase of the mental arithmetic task, working memory span was significantly correlated with reaction times for the young adults, but not for the older adults. Indeed, it is feasible that high levels of anxiety during the transfer phase caused impairments in working memory functioning, such that the young adults with larger working memory capacities (and more efficient processing) were better able to cope with the task than those with smaller working memory capacities (and less efficient processing). The fact that significant correlations were found between state/trait anxiety and reaction times for young adults during the transfer phase gives weight to this theory. In the visual numerosity task, the effect of anxiety on working memory functioning may also explain why the amount of initial recovery in the transfer phase was smaller for the young adults than for the older adults. Indeed, it is possible that high levels of state anxiety interfered with central executive functioning in the young age group, which consequently affected their algorithmic processing ability during the initial stages of transfer.

Some of the age differences in skill acquisition can also be explained by differences in the speed of information processing (Lincourt et al., 1998). For example, several researchers have proposed that changes in the speed of information-processing with age can explain the reductions in working memory functioning with age, such that speed of information processing provides a better account of age differences in performance than working memory does (Salthouse, 1991; Salthouse, 1992; Salthouse & Coon, 1994). The results of numerous studies investigating the speed of information processing in young and older adults, have found that it generally decreases with age (e.g., Borkan & Norris, 1980; Cerella, 1985; Cerella, Poon, & Williams, 1980). This slower processing speed of older adults may explain why their response times were consistently and significantly slower than younger adults in both the mental arithmetic and visual numerosity tasks. Many theorists have attributed this age-related decline in information processing speed with changes in the neurons of the brain (Cerella, 1990; Myerson, Hale, Wagstaff, Poon, & Smith, 1990; Salthouse, 1985; Welford, 1988). According to Cerella (1990), when neurons die or become damaged with age, the brain creates bypasses so that information processing is not disrupted. These bypasses result in more neuronal connections being created, so that it takes more time for information to be processed. As a consequence, the speed of information processing in older adults becomes slower.

This decreased speed of information processing in older adults can, in turn, cause impairments in cognitive functioning. For example, Salthouse (1996) proposed that it takes longer amounts of time for older adults to carry out early cognitive processes in the brain, such that they then have less time to perform later processes. As a result, the later cognitive processes are often only partially executed and are less effective. Furthermore, the products of early processes are often lost through decay or displacement by the time the later processes are executed. Thus, important information is often no longer available when it is needed. As a result of these mechanisms, older adults often perform more poorly than younger adults in many cognitive tasks. Therefore, age differences in speed of information processing may be able to explain the age differences in reaction time found in the mental arithmetic and visual numerosity tasks. Future experiments in the area of skill acquisition and aging could administer measures such as the Digit Symbol Coding subtest or the Symbol Search subtest from the Wechsler Adult Intelligence Scale – Third Edition (Wechsler, 1997) to young and older adults, to determine whether age differences exist in their speed of information processing, and whether they are related to age differences in performance.

The results from Experiments 1 and 2 can also be explained in terms of biological factors, such as age-related changes in the visual system, the nervous system and the brain. For example, in both the mental arithmetic task and the visual numerosity task, the performance of older adults was generally slower than that of younger adults, the benefits of practice on reaction time were generally greater for young adults than for older adults, and the learning rates of young adults were consistently faster than those of older adults. These impairments in the performance of older adults may be attributed to the fact that both tasks involved the presentation of visual stimuli on a computer screen, and older adults are more likely to have impaired vision compared to younger adults. For example, aging is associated with impaired visual acuity (Fozard, 1990), impaired contrast sensitivity (Fozard, 1990), far-sightedness (Botwinick, 1984), and a diminished ability to discriminate between colours (Botwinick, 1984). Furthermore, the speed of smooth pursuit and saccadic eye movements seems to decrease significantly with age (Moschner & Baloh, 1994). This has a considerable effect on the visual tracking rate of older adults. Several studies have also found that the useful field of view (i.e., the total area in which visual information can be acquired with one eye fixation) reduces in size with age (Ball, Beard, Roenker, Miller, & Griggs, 1988; Scialfa, Kline, & Lyman, 1987). This suggests that older adults are limited in how much information they can extract during a given fixation. The implication is also that older adults observe smaller sections of a given visual scene, and scan each section more slowly, compared to younger adults. Therefore, the performance of older adults in Experiments 1 and 2 may have been affected by impairments in their vision. Future research in the area of aging and skill acquisition could include measures of visual acuity or visual tracking to determine whether age differences in performance are related to age differences in the visual system.

The impairments in performance experienced by older adults may also be attributed to age-related changes in the brain and nervous system. For example, aging is associated with a loss of brain tissue, with about 5 percent of the brain's mass lost by age 70, 10 percent lost by age 80, and 20 percent lost by age 90 (Ivy, MacLeod, Petit, & Markus, 1992; Wisniewski & Terry, 1976). The most affected areas of neuronal loss seem to be the frontal lobes (Ivy et al., 1992), which have been identified by Baddeley (1986) as the areas responsible for the central executive functioning of working memory. The hippocampus, a structure found in the limbic system and involved in memory function, is also thought to deteriorate with age (Mosocitch & Winocur, 1992). However, some studies have found that the neuronal loss in the cortex and the hippocampus is not extensive (e.g., Smith, Roberts, Gage, & Tuszynski, 1999). There is also a great deal of variation between individuals of similar ages, such that some individuals over 60 years of age show no significant neuronal loss, while others do. Therefore other factors, such as the amount of mental activity performed by the individual and the amount of oxygen in the brain, may be responsible for neuronal loss.

However, while there is a general consensus that the loss of nerve cells occurs with age, there is also increasing evidence to support the notion of brain plasticity. That is, the brain is able to modify its structure and function positively in response to damage or learning experiences (Cotman, 1990). For example, one of the mechanisms that the brain uses to cope with neuronal loss is the redundancy of neurons. Thus, many neurons (or nerve cells) carry out similar activities so that if one neuron dies or becomes damaged, another one can replace it and carry out its function. Another compensatory mechanism of the brain is axonal and dendritic sprouting. Both the axon and dendrites are fibres that extend away from the neuronal body – the axon transmits information to other parts of the system while the dendrites receive information from other parts of the system (Lemme, 2002). When nerve cells die, there is evidence to suggest that the surrounding neurons develop or 'sprout' new dendrites and new axons in order to fill the space. In this way, brain function is not lost (Cotman, 1990).

This sprouting mechanism has been observed in response to environmental enrichment (Turner & Greenough, 1985) and learning (Greenough, 1984, 1988). For example, when rats are moved from a standard laboratory environment to a more exciting environment with novel objects and social contact, the cortex of their brains becomes thicker, and there is more extensive dendritic sprouting (Black, Greenough, Anderson, & Isaacs, 1987; Woodruff-Pak, 1993). It has therefore been suggested that environmental stimulation increases the neuronal connections in the brain whereas decreased stimulation decreases the neuronal connections and functional capacity of the brain (Diamond, 1993). This increase in neuronal connections seems to occur when learning new tasks as well. For example in a study by Greenough, Larson and Withers (1985), the researchers trained adult rats for 16 days to reach food using their nonpreferred paw. The training resulted in neuronal changes in the brains of the rats, such that the network of dendrites for the neurons controlling the nonpreferred paw became as complex as that controlling the preferred paw.

The issue of brain plasticity and compensation may apply to the older adults who participated in the present experiments. These older adults were volunteers from the community, who seemed to be physically and mentally active. They were able to become significantly faster with practice in both experimental tasks (indicating that they could learn new tasks), they generally improved as much as younger adults with practice, they achieved the same or better levels of accuracy compared to younger adults, they were capable of general and specific learning, they were capable of transferring skills from one task to another, and their working memory functioning was sufficient to perform the tasks. These results imply that mentally active older adults are capable of learning new cognitive and perceptual skills, and are able to match the performance levels of young adults in some areas. It is possible that the older adults in the present experiments achieved these results due to the neuronal changes occurring in their brains, from a lifetime of experience and learning. Thus, even if neuronal loss occurred during the lives of these older adults, it is likely that their active lifestyles resulted in high levels of environmental stimulation, which subsequently caused increases in the neuronal connections of their brains (Diamond, 1993). Thus, it is possible that a deterioration in brain mass and function with age would traditionally cause older adults to experience difficulty in learning and performing mental arithmetic and visual numerosity. However, the brain's compensatory mechanisms may have minimised the functional impairments of the older adults in the present experiments, such that they were still capable of learning new skills, and were capable of achieving the same levels of performance as younger adults in some areas.

The implications of these results are that active older adults are immune to the detrimental effects of aging in certain respects. Thus, even with the negative biological and cognitive changes that usually occur with aging, the older adults in the present experiments were able to learn novel tasks, they were able to improve as much as younger adults with practice, and they were able to achieve the same or better levels of accuracy compared to younger adults. The older adults in the present experiments also learned new skills in a similar way to the younger adults, using a combination of specific and general learning, which implies that both younger and older adults can be taught skills in a similar way. Furthermore, the older adults in the present experiments seemed as capable of transferring skill from one task to another as younger adults, and this ability to adapt makes them as valuable in the workplace as younger adults when assigned to new tasks. The general lack of correlations between working memory span and reaction time for older adults also suggests that their working memory functioning was sufficient to perform the tasks given, and that perhaps working memory functioning remains intact in active older adults. The lower anxiety levels of older adults may also explain why anxiety did not interfere with their working memory functioning during skill acquisition, whereas it did for the younger adults. This interference in working memory functioning for the younger adults may explain why their performance was inferior to that of older adults in certain areas. Therefore, it seems that age differences in working memory and anxiety can be related to age differences in skill acquisition and transfer. In fact, working memory functioning and anxiety may be more relevant for predicting differences in skill acquisition than age itself. Indeed, it is clear from our results that aging does not necessarily cause differences in skill acquisition, since younger and older adults obtained equivalent results in many aspects of learning. The fact that healthy, active older adults were capable of learning, performing and transferring new skills ultimately suggests that aging is not synonymous with an inevitable decline in functioning.

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Appendix A

Table A1. *Past and Present Occupations of Older Participants in Experiment 1: A Frequency Table.*

Occupation	Frequency
Managerial	5
Professional	15
Business/Retail	7
Secretarial/Clerical	8
Home Duties	3
Factory/Agriculture	4
Trades Person	1
Total	43

Appendix B

Figure B1. State Anxiety Questionnaire 1 (STAI-1) from Spielberger, Gorsuch, Lushene, Vagg, & Jacobs (1983). Copyright permission obtained.

SELF EVALUATION QUESTIONNAIRE **STAI Form Y-2 (PART 1)**

Please provide the following information:

Name________________________ Date__________ S_____

Age______________ Gender *(Circle)* **M F** T_____

DIRECTIONS:

A number of statements which people have used to describe themselves are given below. Read each statement and then circle the appropriate number to the right of the statement to indicate how you feel *right now*. That is, *at this moment*. There are no right or wrong answers. Do not spend to much time on any one statement but give the answer which seems to describe your present feelings best.

		NOT AT ALL	SOMEWHAT	MODERATELY SO	VERY MUCH SO
1.	I feel calm	1	2	3	4
2.	I am tense	1	2	3	4
3.	I feel at ease	1	2	3	4
4.	I am presently worrying over possible misfortunes	1	2	3	4
5.	I feel frightened	1	2	3	4
6.	I feel self-confident	1	2	3	4
7.	I am jittery	1	2	3	4
8.	I am relaxed	1	2	3	4
9.	I am worried	1	2	3	4
10.	I feel steady	1	2	3	4

Figure B2. State Anxiety Questionnaire 2 (STAI-2) from Spielberger et al. (1983).

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SELF EVALUATION QUESTIONNAIRE

STAI Form Y-2 (PART 2)

Please provide the following information:

Name________________________ Date__________ S_____

Age__________ Gender *(Circle)* **M F** T _____

DIRECTIONS:

A number of statements which people have used to describe themselves are given below. Read each statement and then circle the appropriate number to the right of the statement to indicate how you feel *right now*. That is, *at this moment*. There are no right or wrong answers. Do not spend to much time on any one statement but give the answer which seems to describe your present feelings best.

		NOT AT ALL	SOMEWHAT	MODERATELY SO	VERY MUCH SO
1.	I feel secure	1	2	3	4
2.	I feel strained	1	2	3	4
3.	I feel upset	1	2	3	4
4.	I feel satisfied	1	2	3	4
5.	I feel comfortable	1	2	3	4
6.	I feel nervous	1	2	3	4
7.	I feel indecisive	1	2	3	4
8.	I feel content	1	2	3	4
9.	I feel confused	1	2	3	4
10.	I feel pleasant	1	2	3	4

Appendix C

Trait Anxiety Questionnaire from Spielberger et al. (1983)

SELF-EVALUATION QUESTIONNAIRE

STAI Form Y-2

Name________________________________ Date__________

DIRECTIONS

A number of statements which people have used to describe themselves are given below. Read each statement and then circle the appropriate number to the right of the statement to indicate how you *generally* feel. There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe how you generally feel.

	ALMOST NEVER	SOMETIMES	OFTEN	ALMOST ALWAYS
21. I feel pleasant	1	2	3	4
22. I feel nervous and restless	1	2	3	4
23. I feel satisfied with myself	1	2	3	4
24. I wish I could be as happy as others seem to be	1	2	3	4
25. I feel like a failure	1	2	3	4
26. I feel rested	1	2	3	4
27. I am "calm, cool, and collected"	1	2	3	4
28. I feel that difficulties are piling up so that I cannot overcome them	1	2	3	4
29. I worry too much over something that really doesn't matter	1	2	3	4
30. I am happy	1	2	3	4
31. I have disturbing thoughts	1	2	3	4
32. I lack self-confidence	1	2	3	4
33. I feel secure	1	2	3	4
34. I make decisions easily	1	2	3	4
35. I feel inadequate	1	2	3	4
36. I am content	1	2	3	4
37. Some unimportant thought runs through my mind and bothers me	1	2	3	4
38. I take disappointments so keenly that I can't put them out of my mind	1	2	3	4
39. I am a steady person	1	2	3	4
40. I get in a state of tension or turmoil as I think over my recent concerns and interests	1	2	3	4

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Appendix D

Scoring Instructions for the STAI (Spielberger et al., 1983)

The STAI manual (Spielberger et al., 1983) gives the following instructions:

> Each STAI item is given a weighted score of 1 to 4. A rating of 4 indicates the *presence* of a high level of anxiety for ten s-Anxiety items and eleven T-Axiety items (e.g. "I feel frightened," "I feel upset"). A high rating indicates the *absence* of anxiety for the remaining ten S-Axiety items and nine T-Anxiety items (e.g. "I feel calm", "I feel relaxed"). The scoring weights for the *anxiety-present* items are the same as the blackened numbers on the test form. The scoring weights for the *anxiety-absent* items are reversed, i.e., responses marked 1, 2, 3, or 4 are scored 4, 3, 2 or 1, respectively. The anxiety-absent items for which the scoring weights are reversed on the S-anxiety and T-anxiety scales are:
>
> *STAI-1:* 1, 3, 6, 8, 10. [modified from manual]
>
> *STAI-2:* 1, 4, 5, 8, 10. [modified from manual]
>
> *T-Anxiety:* 21, 23, 26, 27, 30, 33, 34, 36, 39
>
> To obtain scores for the S-Anxiety and T-Anxiety scales, simply add the weighted scores for the .... items that make up each scale, taking into account the fact that the scores are reversed for the above items (p. 4).

Appendix E

Digit Span Task from WAIS-III (Wechsler, 1997)

8. Digit Span

DISCONTINUE RULE
Digits Forward & Backward:
Score of 0 on both trials of any item.
For both Digits Forward & Backward, administer both trials of each item even if Trial 1 is passed. Administer Digits Backward even if examinee scores 0 on Digits Forward.

SCORING RULE
Each Trial: 0 or 1 pt. for each response
Item score = Trial 1 + Trial 2

START

Digits Forward

Item	Trial	Item/Response	Trial Score	Item Score (0, 1 or 2)
1.	1	1-7		
	2	6-3		
2.	1	5-8-2		
	2	6-9-4		
3.	1	6-4-3-9		
	2	7-2-8-6		
4.	1	4-2-7-3-1		
	2	7-5-8-3-6		
5.	1	6-1-9-4-7-3		
	2	3-9-2-4-8-7		
6.	1	5-9-1-7-4-2-8		
	2	4-1-7-9-3-8-6		
7.	1	5-8-1-9-2-6-4-7		
	2	3-8-2-9-5-1-7-4		
8.	1	2-7-5-8-6-2-5-8-4		
	2	7-1-3-9-4-2-5-6-8		

Digits Forward Total Score (Maximum = 16)

Digits Backward

Item	Trial	Item/Response	Trial Score	Item Score (0, 1 or 2)
1.	1	2-4		
	2	5-7		
2.	1	6-2-9		
	2	4-1-5		
3.	1	3-2-7-9		
	2	4-9-6-8		
4.	1	1-5-2-8-6		
	2	6-1-8-4-3		
5.	1	5-3-9-4-1-8		
	2	7-2-4-8-5-6		
6.	1	8-1-2-9-3-6-5		
	2	4-7-3-9-1-2-8		
7.	1	9-4-3-7-6-2-5-8		
	2	7-2-8-1-9-6-5-3		

Digits Backward Total Score (Maximum = 14)

Forward + Backward = (Maximum = 30)

Appendix F

Instructions for Digit Span Task (Wechsler, 1997)

Digits Forward Instructions

"I am going to say some numbers. Listen carefully and when I am through, I want you to say them right after me. Just say what I say."

Digits Backward Instructions

"Now I am going to say some more numbers. But this time when I stop, I want you to say them backward. For example, if I say 7-1-9 what would you say?"

[If subject gives correct answer]: "That's right".

[If subject gives incorrect answer]: "No, you would say 9-1-7. I said 7-1-9 so to say it backward, you would say 9-1-7. Now try these numbers. Remember, you are to say them backward: 3-4-8.

Appendix G

Sentences for the Reading Span Task (Daneman & Carpenter, 1980)

Practice

1. Due to his gross inadequacies, his position as director was terminated abruptly.
2. It is possible, ofcourse, that life did not arise on the earth at all.

---

1. After all he had not gone far, and some of his walking had been circular.
2. The poor lady was thoroughly persuaded that she was not long to survive this vision.

2-Sentence Level

1. Jane's relatives had decided that her gentleman friend was not one of high status.
2. Without any hesitation, he plunged into the difficult mathematics assignment blindly.

---

1. The entire town arrived to see the appearance of the controversial political candidate.
2. After passing all the exams, the class celebrated for an entire week without resting.

---

1. According to the results of the survey, this man is the most liked Hollywood star.
2. The weather was unpredictable that summer so no-one made plans too far in advance.

Sentences for the Reading Span Task (continued)

3-Sentence Level

1. The devastating effects of the flood were not fully realized until months later.
2. In a moment of complete spontaneity, she developed a thesis for her paper.
3. At the conclusion of the long evening, the enthusiastic crowd applauded.

---

1. They attended the theatre habitually except for circumstances beyond their control.
2. The men worked long hours in order to obtain the necessary amount of wood.
3. The old lady talked to her new neighbor on her weekly walks from church.

---

1. There are days when the city where I live wakes in the morning with a strange look.
2. We boys wanted to warn them, but we backed down when it came to the pinch.
3. With shocked amazement and appalled fascination Marion looked at the pictures.

4-Sentence Level

1. I found the keynote speaker incredibly boring, inarticulate and not well read.
2. In order to postpone the business trip, he cancelled his engagements for the week.
3. The incorrigible child was punished brutally for his lack of respect for his elders.
4. The brilliant trial attorney dazzled the jury with his astute knowledge of the case.

Sentences for the Reading Span Task (continued)

1. I imagine that you have a shrewd suspicion of the object of my earlier visit.
2. I turned my memories over at random like pictures in a photograph album.
3. I'm not certain what went wrong but I think it was my cruel and bad temper.
4. Filled with these dreary forebodings, I fearfully opened the heavy wooden door.

---

1. Sometimes I get so tired of trying to convince him that I love him and shall forever.
2. When in trouble, children naturally hope for a miraculous intervention by a superhuman.
3. It was your belief in the significance of my suffering that kept me going.
4. The girl hesitated for a moment to taste the onions because her husband hated the smell.

5-Sentence Level

1. A small oil lamp burned on the floor and two men crouched against the wall, watching me.
2. The products of digital electronics will play an important role in your future.
3. One problem with this explanation is that there appears to be no defense against cheating.
4. Sometimes the scapegoat is an outsider who has been taken into the community.
5. I should not be able to make anyone understand how exciting it all was.

Sentences for the Reading Span Task (continued)

---

1. In a flash of fatigue and fantasy, he saw a fat Indian sitting beside a campfire.
2. The lieutenant sat beside the man with the walkie-talkie and stared at the muddy ground.
3. I will not shock my readers with a description of the cold-blooded butchery that followed.
4. The courses are designed as much for professional engineers as for amateur enthusiasts.
5. The taxi turned up the avenue, where they had a clear view of the lake.

---

1. The words of human love have been used by the group to describe their vision of God.
2. It was shortly after this that an unusual pressure of business called me into town.
3. He pursued this theme, still pretending to seek for information to quiet his own doubts.
4. I was so surprised at this unaccountable apparition, that I was speechless for a while.
5. When at last his eyes opened, there was no gleam of triumph, no shade of anger.

Sentences for the Reading Span Task (continued)

6-Sentence Level

1. The announcement of it resounded throughout the world, penetrated to the remotest land.
2. To do so in directions that are adaptive for mankind would be a realistic objective.
3. Slicing it out carefully with his knife, he folded it without creasing the face.
4. He laughed sarcastically and looked as if he could have poisoned me for my errors.
5. He tolerated another intrusion and thought himself a paragon of patience for doing so.
6. The reader may suppose that I had other motives, besides the desire to escape the law.

---

1. He thought carefully because he had the weird impression that he knew the voices.
2. The basic characteristic of the heroes in the preceding stories is their sensitivity.
3. His imagination had so abstracted him that his name was called twice before he answered.
4. He had an odd elongated skull which sat on his shoulders like a pear on a dish.
5. He stuffed his denim jacket into his pants and fastened the stiff, new snaps securely.
6. On the desk where she wrote her letters was a clutter of objects coated in dust.

Sentences for the Reading Span Task (continued)

1. He had patronized her when she was a child and teased her when she was a student.
2. The rain and howling wind kept beating against the rattling window panes.
3. He covered his heart with both hands to keep anyone from hearing the noise it made.
4. The stories all deal with a middle-aged protagonist who attempts to withdraw from society.
5. Without tension there could be no balance either in nature or in mechanical design.
6. I wish there existed someone to whom I could say that I felt very sorry.

Appendix H

Instructions for the Reading Span Task (Daneman & Carpenter, 1980)

"This test should take about 6 to 10 minutes, and we are going to use the pages in this display book. These pages each have a sentence typed across the middle of them, and I am going to turn them over one at a time, and you have to read the sentence aloud. Okay? When you come to a blank card, this signals the end of the set, and at this point you have to say, out loud, the last word of each sentence in the set. Okay? Try to say the words in the order that they appeared without saying the last word first. "

"Now, we're going to start with 2 sentences in each set, but as we go on the number is going to increase. I'll let you know when we switch to a greater number of sentences."

"Although I don't mind how fast or slow you read, you have to start reading the page as soon as I flip it over."

"Any questions? This is a difficult test, so try to concentrate, and don't get discouraged if you can't remember all the words. Ready?"

[If the subject has trouble understanding these instructions, you can illustrate by making up two sentences and telling them what the correct two-word response should be.]

Appendix I

Computer Instructions for the Arithmetic Task

In this experiment you will be presented with a small arithmetic problem such as the following:

$$\frac{x^2 - y}{2} = A$$

$$x = 10 \qquad y = 2$$

Your task is to substitute the values for x and y into the formula to determine a value for A.

Once you have calculated a value for A you then need to decide whether this value is an even or an odd number.

If A is an odd number, you should press the red key labelled 'O' on the keyboard. If A is an even number, you should press the red key labelled 'E' on your keyboard. Please respond as quickly and as accurately as you can.

You will now have some practice trials to make sure that you understand the task.

Please press the space bar to continue.

Appendix J

Informed Consent Sheet

The experiment in which you are about to participate is being conducted by Isabelle Valk (student researcher) and Dr Craig Speelman (principal investigator), from the School of Psychology at Edith Cowan University (Joondalup). This research is designed to measure the way in which people learn a new skill. The project conforms to the guidelines set out by the Edith Cowan University Human Research Ethics Committee.

In this experiment you will be asked to complete a number of questionnaires and memory tasks given by the experimenter. This will be followed by a computer generated task in which you will be required to respond with a simple response on a keyboard. Only a basic knowledge of computers is required. If you have never done anything like this before you should not worry, because most people will feel the same as you in this respect. The aim of this experiment will be to see how well you perform the task with time, and how the performance of your age group will compare with the performance of a different age group. This research will hopefully lead to discoveries about how age affects the way in which people learn new tasks. You will only need to participate in one session, and the session will only last about 90 minutes.

Informed Consent Sheet (Continued)

Please be assured that any information you provide will be kept strictly confidential by the researcher. At the conclusion of this study, a report of the results will be written up, and available upon request. No identifying information will be included in this report. All data will be reported in group form only.

Please understand that your participation in this research is totally voluntary, and that even if you have agreed to participate in this research, you are free to withdraw at any time. You are also free to remove any data that you have contributed to the study.

If you have any questions concerning this project, please contact Dr Craig Speelman (Principal Investigator) at the School of Psychology on [redacted]

I ____________________ have read the information above and any questions I have asked have been answered to my satisfaction. I agree to participate in this activity, realising that I may withdraw at any time. I agree that research data gathered for the study may be published, provided I am not identifiable.

________________________________ ______________

Participant Date

________________________________ ______________

Investigator Date

Appendix K

Participant Detail Sheet

PLEASE NOTE: ALL INFORMATION PROVIDED WILL REMAIN CONFIDENTIAL

Name: ______________________________

Age: _________________

Occupation (past and/or present): ____

When did you retire (if applicable)? _______________________________________

Number of years of formal schooling: ____________________________

Is English your native language?

YES NO

If no, please indicate your native language: ________________________

Are you taking any medications that might cause drowsiness or might affect your performance today?

YES NO

If yes, please provide details of the medications below:

____

____

____

Participant Detail Sheet (Continued)

Do you have any health problems that might affect your performance today?

YES NO

If yes, please provide details in the space below:

____

____

____

What are your hobbies? (please circle)

Bowling

Chess

Doing crosswords

Gardening

Handywork

Playing board games

Playing cards

Reading

Walking

Other ____

Appendix L

Table L1. *Mean Reaction Times (RT) and Standard Deviations (SD) of Young Adults in the Training Phase of Experiment 1 (in ms).*

Block	Mean RT	SD	Block	Mean RT	SD
1	12103	6511	16	3302	1889
2	9175	4535	17	3085	1589
3	8148	3854	18	3184	1788
4	7108	3241	19	3089	1633
5	6456	3283	20	2902	1760
6	5896	3132	21	2676	1411
7	5715	2755	22	2780	1290
8	5182	2681	23	2628	1331
9	4810	2434	24	2677	1375
10	4726	2493	25	2578	1510
11	4461	2569	26	2499	1414
12	4336	2944	27	2326	1341
13	3765	1906	28	2373	1262
14	3712	1904	29	2464	1487
15	3401	1689	30	2165	1164

Table L2. *Mean Reaction Times (RT) and Standard Deviations (SD) of Young Adults in the Transfer Phase of Experiment 1 (in ms).*

Block	Mean RT	SD	Block	Mean RT	SD
31	11703	10979	46	2237	1411
32	7531	4655	47	2233	1245
33	6529	4978	48	2061	1268
34	5475	3243	49	2079	1328
35	5153	3076	50	1932	1169
36	4213	2575	51	1849	1196
37	3868	2475	52	1765	890
38	3766	2238	53	1803	1173
39	3178	1984	54	1810	1118
40	2936	1780	55	1769	1035
41	2846	1854	56	1801	1172
42	2656	1948	57	1687	1012
43	2541	1469	58	1716	1206
44	2384	1195	59	1754	1143
45	2247	1107	60	1665	957

Appendix M

Table M1. *Mean Reaction Times (RT) and Standard Deviations (SD) of Older Adults in the Training Phase of Experiment 1 (in ms).*

Block	Mean RT	SD	Block	Mean RT	SD
1	13207	6230	16	5304	2027
2	10679	5730	17	5479	2373
3	9354	3700	18	5066	1943
4	8571	3074	19	4986	1818
5	8651	3610	20	5159	1975
6	7349	2463	21	4877	2037
7	7153	2864	22	4754	1809
8	7140	2682	23	4756	1712
9	6646	2192	24	4732	1633
10	6553	2263	25	4648	1678
11	6380	2901	26	4493	1586
12	5984	2117	27	4496	1795
13	5667	1825	28	4291	1781
14	5696	2046	29	4281	1578
15	5381	1952	30	4182	1560

Table M2. *Mean Reaction Times (RT) and Standard Deviations (SD) of Older Adults in the Transfer Phase of Experiment 1 (in ms).*

Block	Mean RT	SD	Block	Mean RT	SD
31	10580	5467	46	4593	1794
32	7294	3453	47	4234	1594
33	6526	3754	48	4127	1842
34	5940	2618	49	4044	1399
35	5859	2786	50	4178	1408
36	5721	2846	51	4040	1856
37	5618	2355	52	4042	1390
38	5180	2015	53	3632	1125
39	5126	1911	54	3708	1167
40	4852	1666	55	3764	1295
41	4776	1738	56	3750	1493
42	4660	1836	57	3546	1183
43	4591	1660	58	3464	1297
44	4634	1784	59	3508	1187
45	4375	1435	60	3485	1133

Appendix N

Table N1. *Mean Scores and Standard Deviations of Working Memory measures for Young and Older Adults in Experiment 1.*

	Mean	Standard Deviation
		Young Adults (n = 46)
Digits Forward	11.20	2.02
Digits Backward	7.17	1.90
Reading Span	2.43	0.54
		Older Adults (n = 43)
Digits Forward	10.67	1.90
Digits Backward	6.33	1.94
Reading Span	2.33	0.61

Appendix O

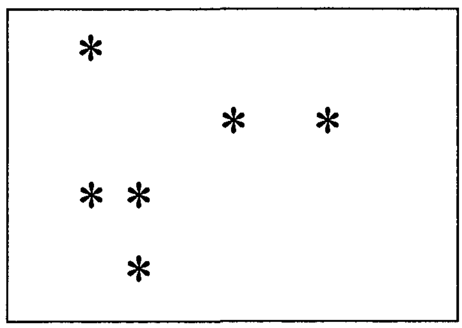
Table O1. *Past and Present Occupations of Older Participants in Experiment 2: A Frequency Table.*

Occupation	Frequency
Managerial	2
Professional	14
Business/Retail	6
Secretarial/Clerical	16
Home Duties	2
Factory/Agriculture	2
Trades Person	4
Carer	1
Total	47

Appendix P

Computer Instructions for the Visual Numerosity Task

In this experiment you will be presented with simple pictures such as the following:



Your task is to count how many stars there are in each picture.

Once you have counted the number of stars, you then need to decide whether this value is an even or an odd number.

If the value is an odd number, you should press the red key labelled ‘O’ on the keyboard. If the value is an even number, you should press the red key labelled ‘E’ on the keyboard. Please respond as quickly and as accurately as you can.

You will now have some practice trials to make sure you understand the task.

Please press the Space Bar to continue.

Appendix Q

Table Q1. *Practice items: Values of x and y coordinates for each visual numerosity level.*

Numerosity Level	6	7	8	9	10	11	12	13
	(2,5)	(7,7)	(4,11)	(3,1)	(6,4)	(11,7)	(6,7)	(6,12)
(x,y)	(4,1)	(12,9)	(7,3)	(7,7)	(3,7)	(6,5)	(9,12)	(12,4)
Coordinates	(7,8)	(3,10)	(5,12)	(1,7)	(6,5)	(7,6)	(9,3)	(5,7)
	(5,3)	(9,11)	(3,7)	(4,9)	(11,12)	(12,9)	(1,4)	(3,10)
	(5,1)	(3,4)	(3,5)	(10,6)	(9,4)	(4,9)	(7,3)	(10,12)
	(7,11)	(8,5)	(9,10)	(6,12)	(11,3)	(2,10)	(12,5)	(7,1)
		(12,12)	(10,8)	(2,11)	(10,1)	(11,4)	(6,5)	(7,3)
			(10,11)	(4,2)	(3,11)	(9,4)	(7,9)	(5,5)
				(2,1)	(6,8)	(2,8)	(2,12)	(9,4)
					(3,6)	(2,2)	(10,3)	(3,6)
						(7,1)	(12,3)	(6,10)
							(8,9)	(11,11)
								(7,5)

Table Q2. *Set 1: Values of x and y coordinates for each visual numerosity level.*

Numerosity Level	6	7	8	9	10	11	12	13
	(10,12)	(5,5)	(6,5)	(11,12)	(8,11)	(2,6)	(5,3)	(7,5)
(x,y)	(7,2)	(7,6)	(9,5)	(2,2)	(12,6)	(4,6)	(10,3)	(5,1)
Coordinates	(10,4)	(3,2)	(5,11)	(10,9)	(10,8)	(11,11)	(9,5)	(8,7)
	(2,3)	(10,5)	(6,3)	(6,4)	(12,11)	(8,4)	(10,7)	(1,5)
	(9,10)	(8,7)	(4,11)	(8,9)	(3,4)	(5,11)	(4,5)	(2,4)
	(9,2)	(8,9)	(3,5)	(3,11)	(6,9)	(10,9)	(10,10)	(7,11)
		(9,2)	(2,2)	(9,4)	(3,9)	(12,11)	(4,3)	(9,6)
			(4,8)	(11,3)	(10,3)	(8,3)	(9,10)	(9,5)
				(6,9)	(1,10)	(2,9)	(5,8)	(7,9)
					(7,5)	(2,11)	(7,9)	(1,9)
						(9,7)	(1,3)	(10,1)
							(5,4)	(10,4)
								(3,3)

Table Q3. *Set 2: Values of x and y coordinates for each visual numerosity level.*

Numerosity Level	6	7	8	9	10	11	12	13
	(10,11)	(7,1)	(5,9)	(1,4)	(8,12)	(7,5)	(8,8)	(2,10)
(x,y)	(3,12)	(3,3)	(10,2)	(6,2)	(6,4)	(12,1)	(5,11)	(8,4)
Coordinates	(4,6)	(12,11)	(6,3)	(6,11)	(11,4)	(10,5)	(4,12)	(7,8)
	(12,5)	(9,4)	(2,4)	(7,6)	(2,7)	(2,4)	(7,5)	(6,7)
	(3,11)	(10,6)	(9,10)	(12,4)	(2,11)	(8,5)	(9,8)	(2,9)
	(5,1)	(5,9)	(4,5)	(8,12)	(7,6)	(4,7)	(3,3)	(5,12)
		(11,2)	(6,1)	(4,1)	(3,5)	(6,1)	(12,9)	(9,12)
			(2,6)	(6,12)	(3,10)	(11,4)	(5,4)	(4,2)
				(4,8)	(9,8)	(10,11)	(2,5)	(4,12)
					(2,9)	(8,4)	(11,7)	(7,10)
						(11,1)	(6,3)	(3,12)
							(9,6)	(10,5)
								(10,8)

Appendix R

Table R1. *Mean Reaction Times (RT) and Standard Deviations (SD) of Young Adults in the Training Phase of Experiment 2 (in ms).*

Block	Mean RT	SD	Block	Mean RT	SD
1	3611	845	16	2584	678
2	3414	788	17	2563	806
3	3303	719	18	2485	690
4	3263	773	19	2423	689
5	3289	776	20	2387	703
6	3122	761	21	2356	769
7	2977	712	22	2314	696
8	3074	726	23	2315	756
9	2985	769	24	2242	736
10	2885	787	25	2270	798
11	2877	842	26	2226	777
12	2762	692	27	2184	829
13	2653	647	28	2092	753
14	2715	780	29	2081	758
15	2594	699	30	2008	704

Table R2. *Mean Reaction Times (RT) and Standard Deviations (SD) of Young Adults in the Transfer Phase of Experiment 2 (in ms).*

Block	Mean RT	SD	Block	Mean RT	SD
31	3365	895	46	1842	754
32	3017	719	47	1803	741
33	2968	869	48	1805	726
34	2711	683	49	1734	708
35	2573	734	50	1750	810
36	2453	811	51	1721	879
37	2271	746	52	1750	795
38	2255	844	53	1625	698
39	2072	744	54	1630	699
40	2145	812	55	1636	735
41	2054	739	56	1664	701
42	2016	723	57	1564	797
43	1998	716	58	1627	779
44	1995	790	59	1531	672
45	1915	724	60	1590	783

Appendix S

Table S1. *Mean Reaction Times (RT) and Standard Deviations (SD) of Older Adults in the Training Phase of Experiment 2 (in ms).*

Block	Mean RT	SD	Block	Mean RT	SD
1	5221	1399	16	4359	1314
2	5016	1366	17	4374	1399
3	4830	1293	18	4343	1446
4	4840	1224	19	4383	1327
5	4790	1274	20	4183	1294
6	4675	1316	21	4306	1222
7	4592	1230	22	4230	1395
8	4656	1650	23	4298	1351
9	4530	1393	24	4129	1208
10	4444	1495	25	4246	1448
11	4479	1416	26	4075	1193
12	4558	1556	27	3987	1222
13	4408	1221	28	4072	1364
14	4457	1437	29	4016	1035
15	4240	1226	30	4055	1105

Table S2. *Mean Reaction Times (RT) and Standard Deviations (SD) of Older Adults in the Transfer Phase of Experiment 2 (in ms).*

Block	Mean RT	SD	Block	Mean RT	SD
31	5316	1147	46	4154	1396
32	4425	1019	47	4027	1339
33	4349	1160	48	4056	1309
34	4345	1169	49	4173	1349
35	4337	1193	50	4028	1295
36	4261	1051	51	3977	1298
37	4306	1197	52	4019	1252
38	4202	1336	53	3957	1405
39	4189	1339	54	3979	1290
40	4122	1154	55	3949	1112
41	4118	1243	56	3948	1359
42	4050	1145	57	3949	1392
43	4068	1269	58	3879	1303
44	4042	1074	59	3851	1191
45	3989	1245	60	3858	1233

Appendix T

Table T1. *Mean Scores and Standard Deviations of Working Memory measures for Young and Older Adults in Experiment 2.*

	Mean	Standard Deviation
	Young Adults (n = 48)	
Digits Forward	11.46	2.24
Digits Backward	7.25	2.17
Reading Span	2.58	0.54
	Older Adults (n = 47)	
Digits Forward	10.02	2.36
Digits Backward	6.85	1.92
Reading Span	2.28	0.54